Global aspects of model error, precipitation, dependence on Physics and Resolution

Tropical cyclones

Alternative/additional convection methods

Analysing waves: MJO and gravity waves

To the organizers: Lisa, Arkeli, Colin

Martin Steinheimer, Glenn Shutts, Philippe Lopez, Thomas Jung, Mark Rodwell, Frederic Vitart

planned Resolution upgrades

End 2009: horizontal resolution from T799=25 km to T1279=15 km, EPS at T639

2010: vertical resolution from 91 to 140-150

2011-12: 24h window for 4D-Var

2013: 48h window for 4D-Var

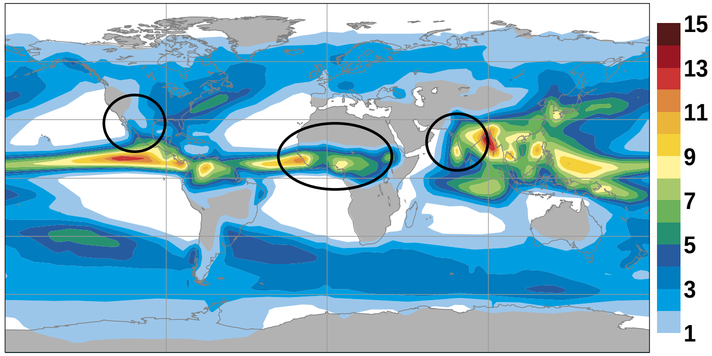
2014-15: horizontal resolution T2000=10 km

Global aspects of model error, precipitation, in long integrations and their dependence on Physics and Resolution

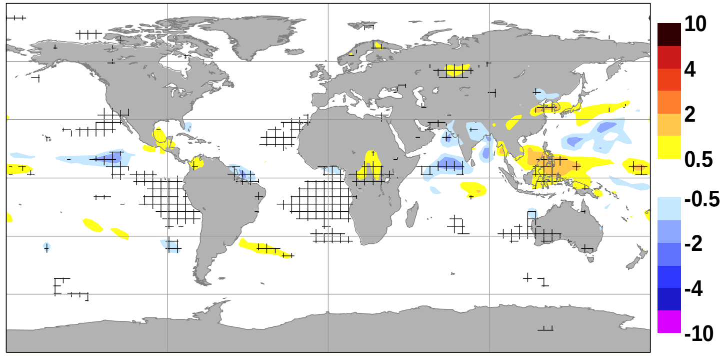
……. And relation with short-range forecast errors

Precipitation JJA: Sensitivity to Model Formulation
Seasonal integrations

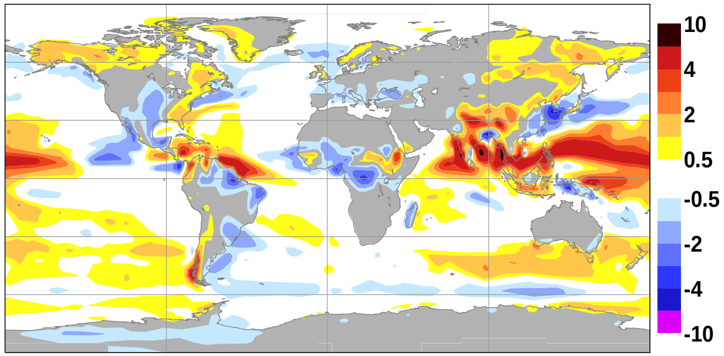
GPCP JJA 1990-2006



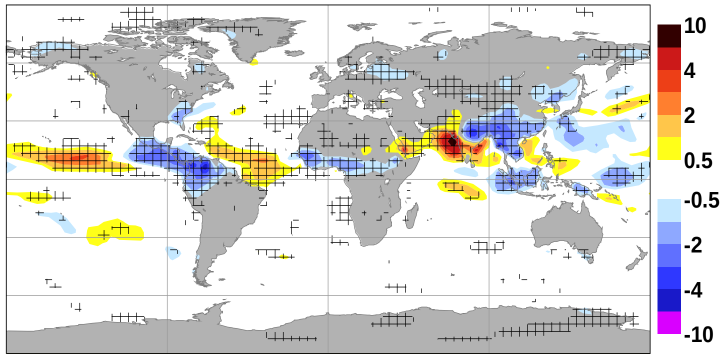
33R1(old vdiff)-33R1



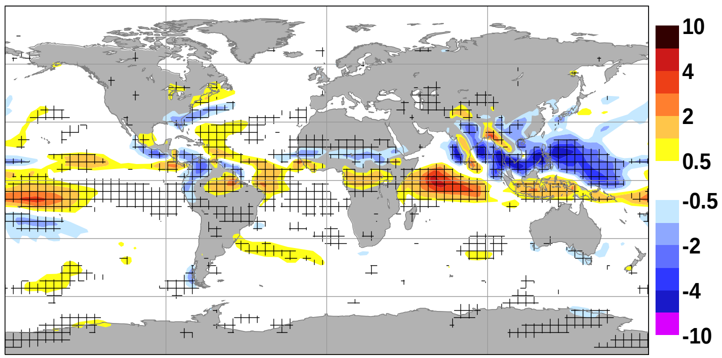
33R1-GPCP



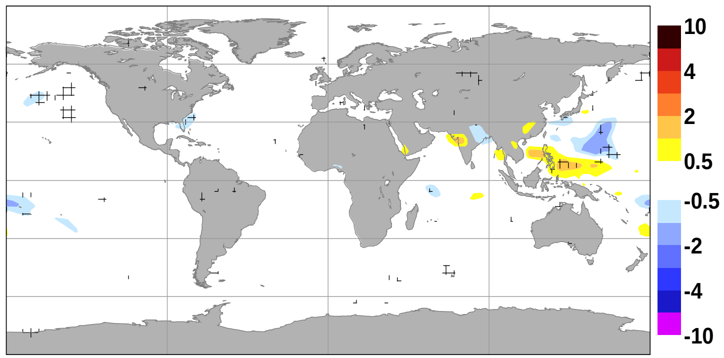
33R1(old radiation)-33R1



33R1(old convection)-33R1

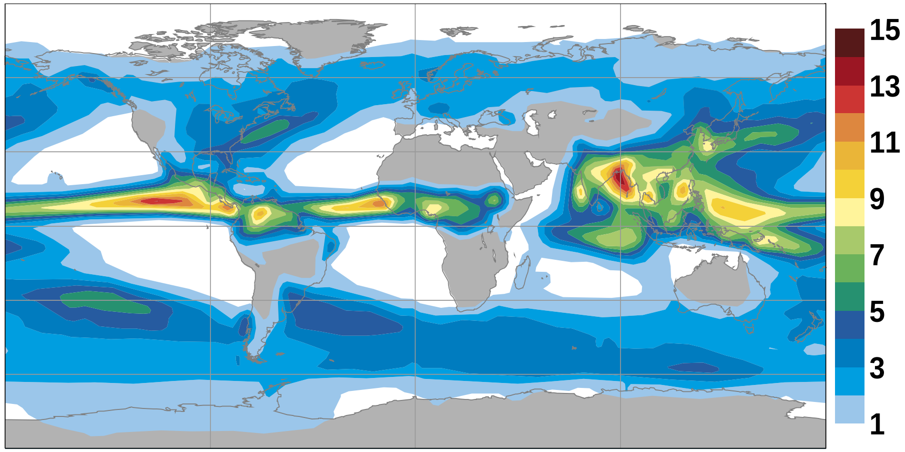


33R1(old soil hydrology)-33R1

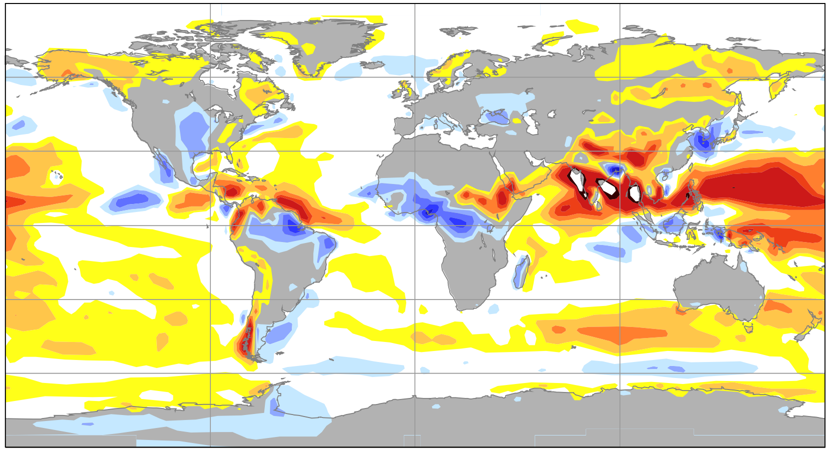


Precipitation JJA: Sensitivity to Resolution
Seasonal Integrations

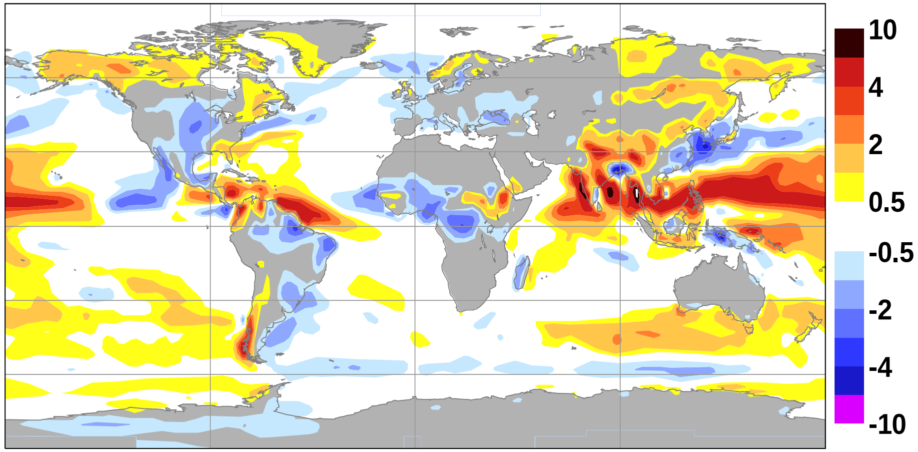
GPCP (JJA 1990-2000)



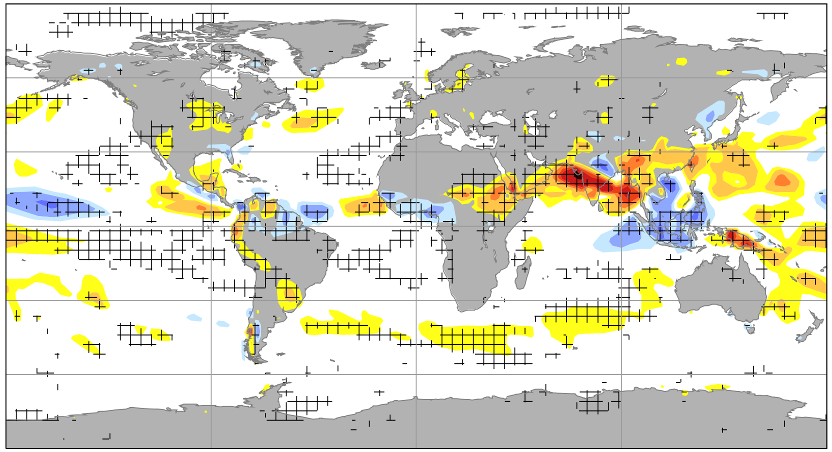
33R1(T_L511)-GPCP



33R1(T_L159)-GPCP



33R1(T_L511)-33R1(T_L159)

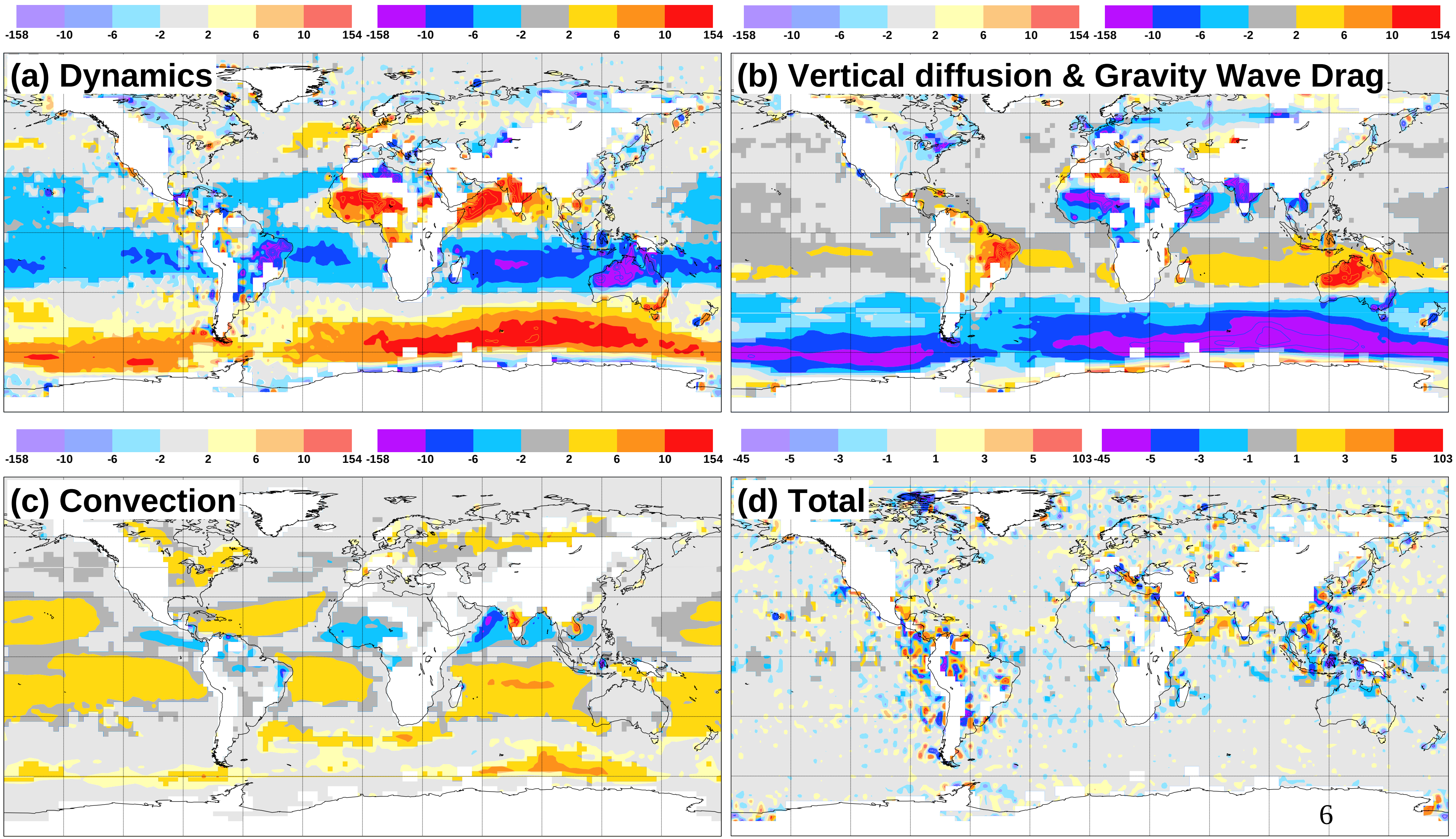


Initial Process Tendencies JJA 2008: U at 925 hPa

High resolution deterministic forecast

33R1

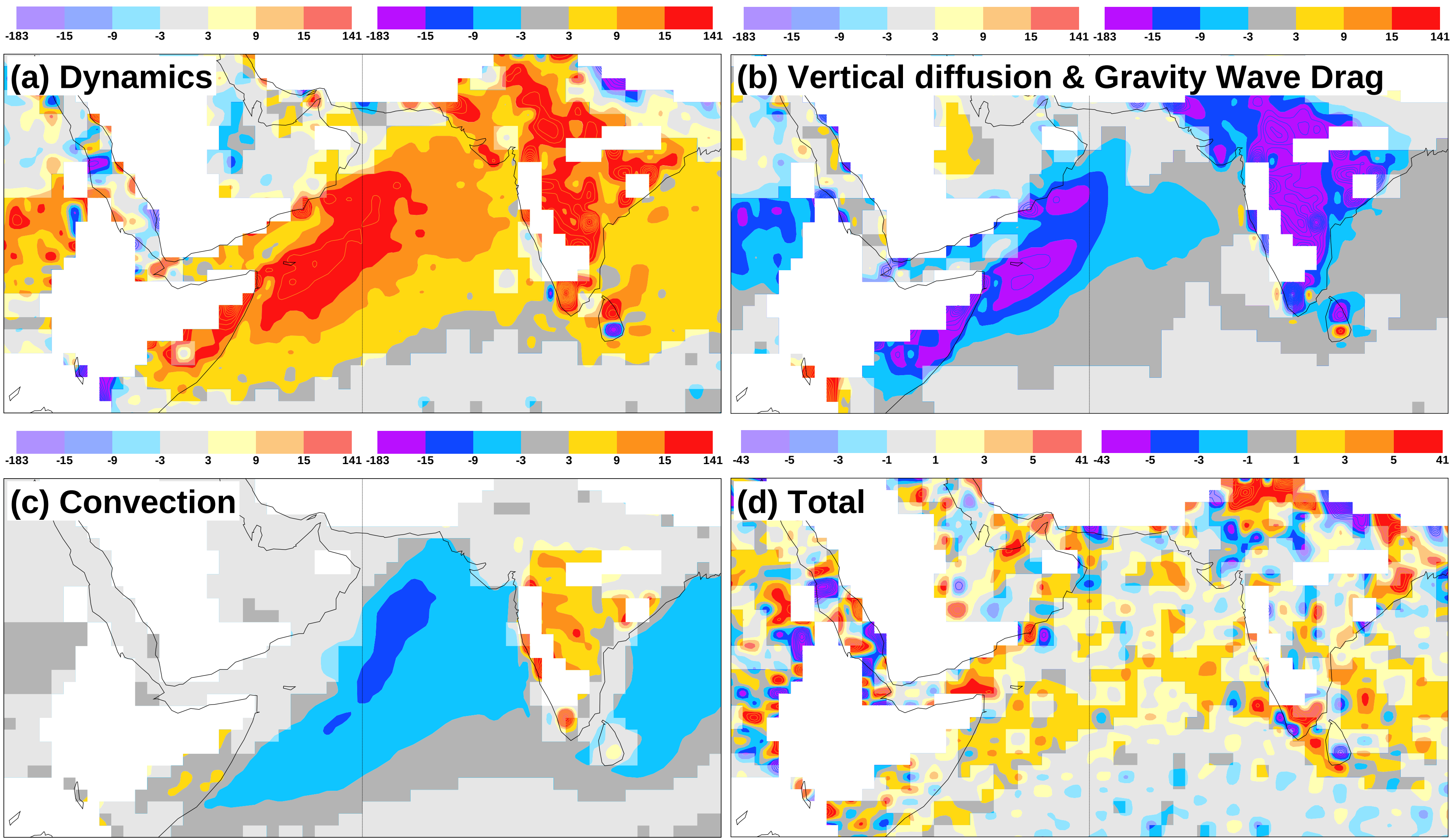
Unit = ms^{-1} over first 24h of forecast



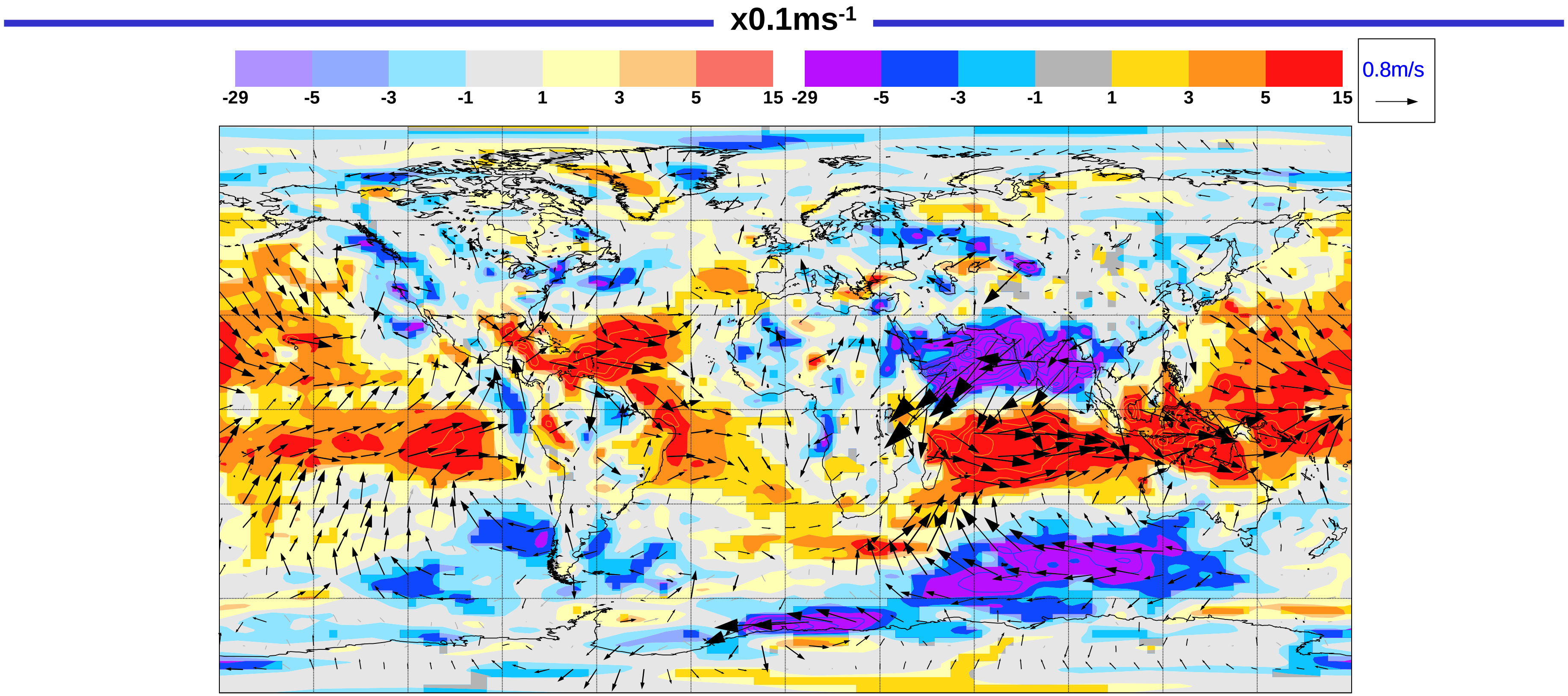
Initial Process Tendencies JJA 2008: U at 925 hPa

33R1

Unit = ms^{-1} over first 24h of forecast



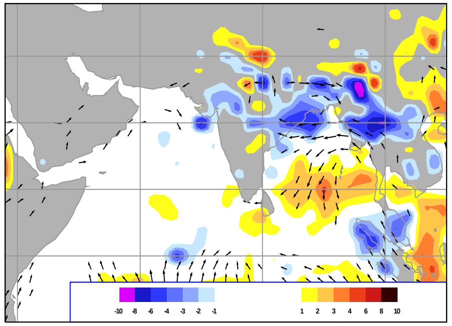
JJA 2008 u and v 925hPa Analysis Increments



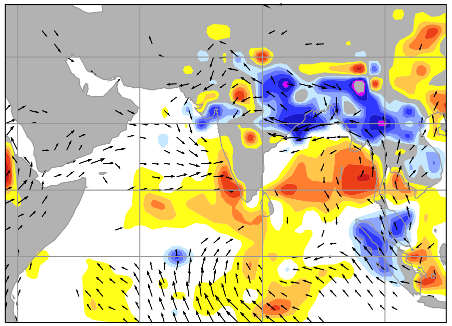
- Analysis Increments indicate that the modelled low-level flow over the Indian Ocean and Arabian Sea (and thus moisture transport into the monsoon) is too strong.
- Are these increments pointing to the root-cause for the monsoon error?

Model Adjustment Day 1-10 : JJA 2008

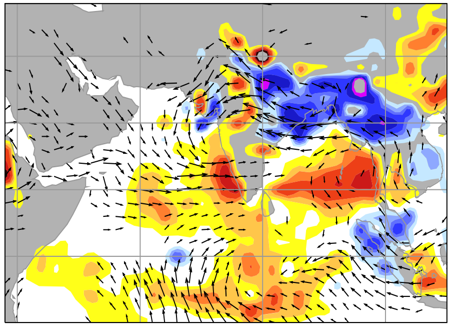
Mean Forecast Difference: D+2 - D+1



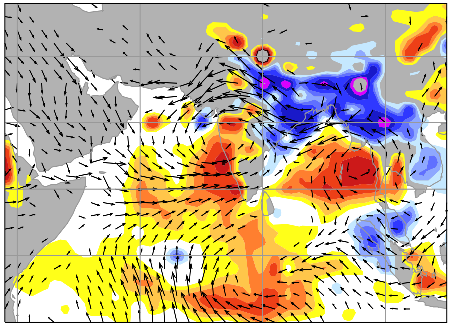
Mean Forecast Difference: D+3 - D+1



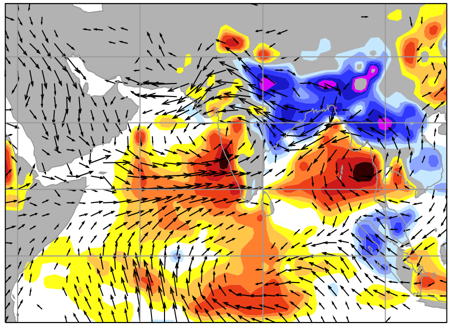
Mean Forecast Difference: D+4 - D+1



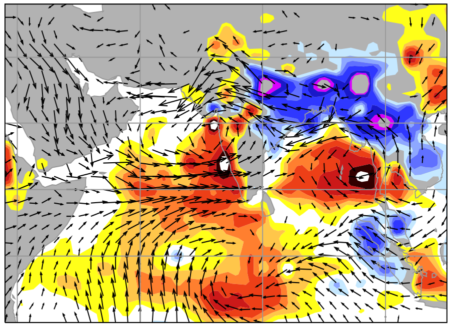
Mean Forecast Difference: D+5 - D+1



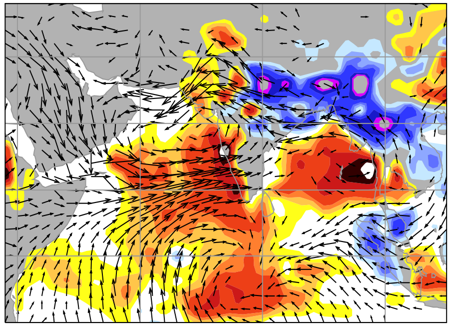
Mean Forecast Difference: D+6 - D+1



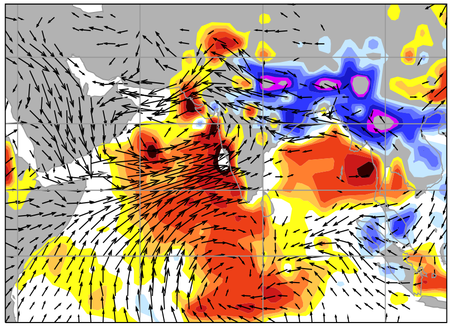
Mean Forecast Difference: D+7 - D+1



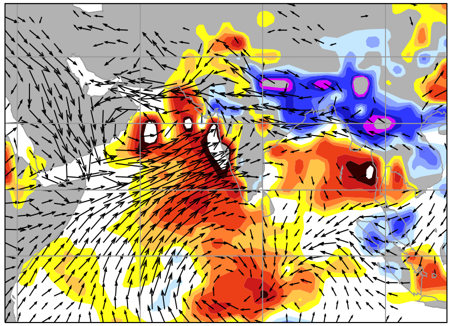
Mean Forecast Difference: D+8 - D+1



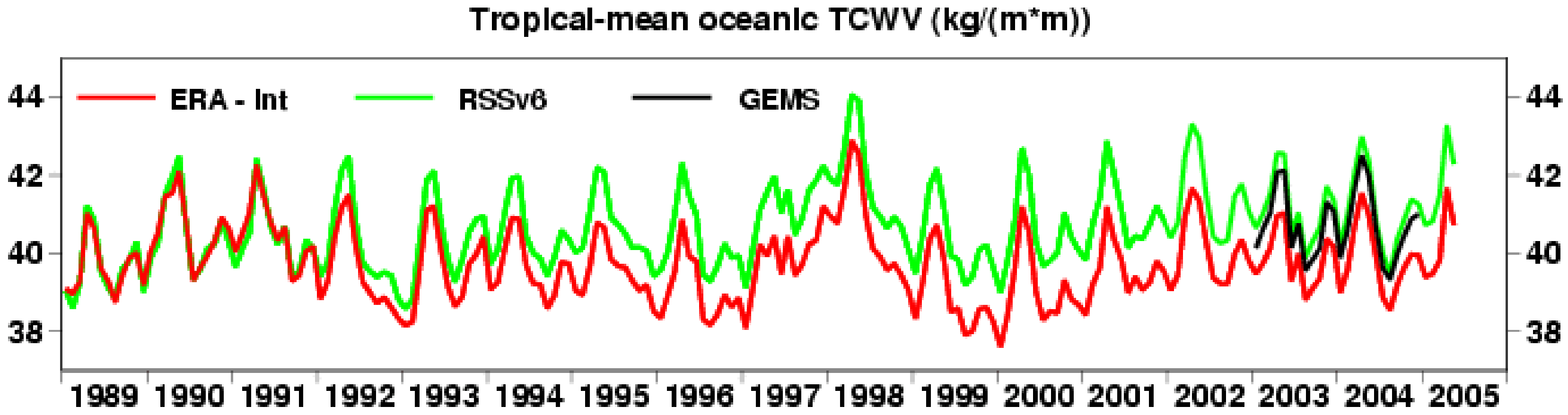
Mean Forecast Difference: D+9 - D+1

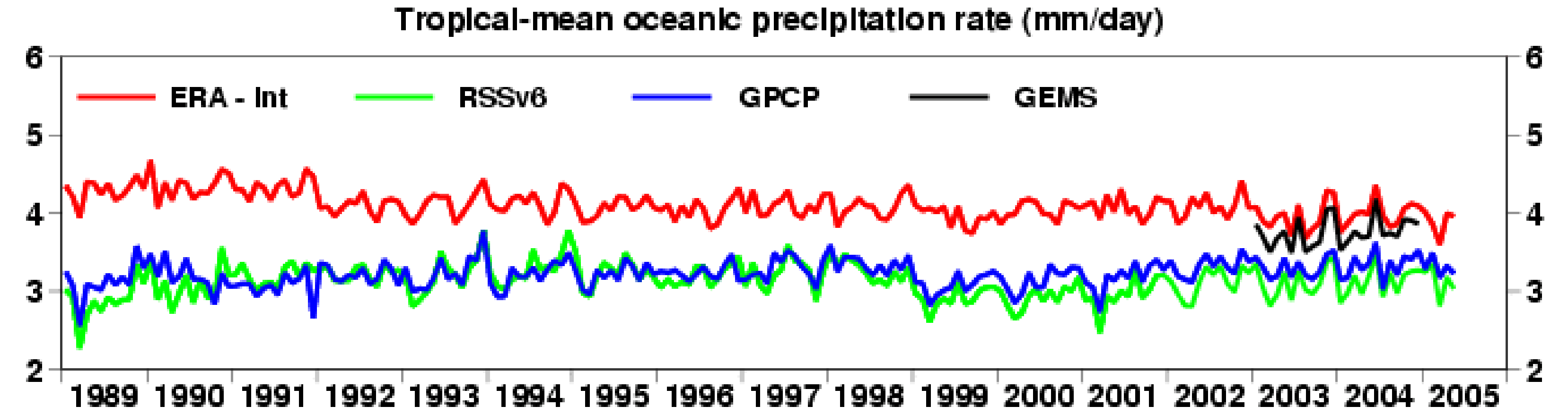


Mean Forecast Difference: D+10 - D+1

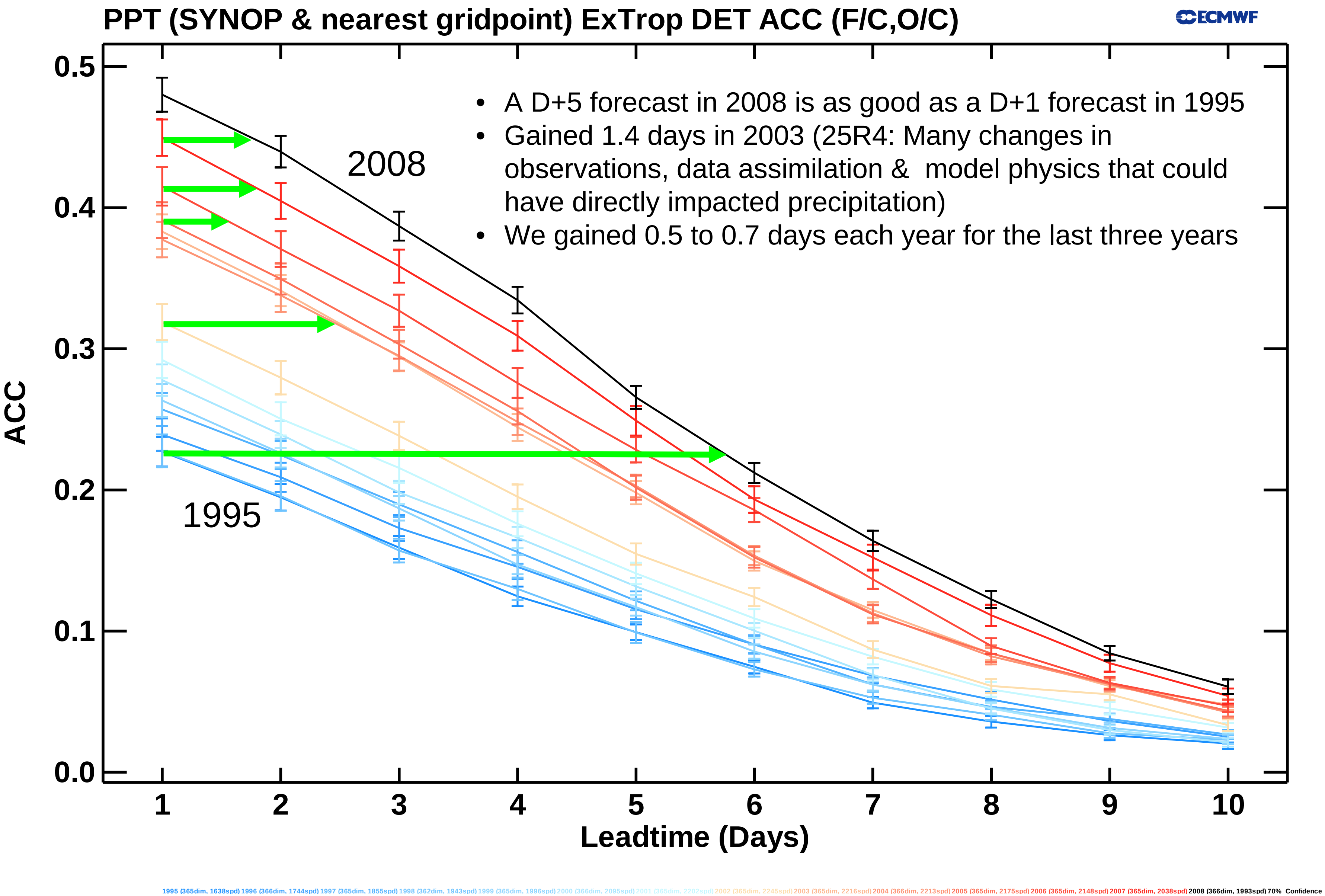


Idem previous but dependence of skill of high-resolution precipitation forecasts on Physics and Resolution

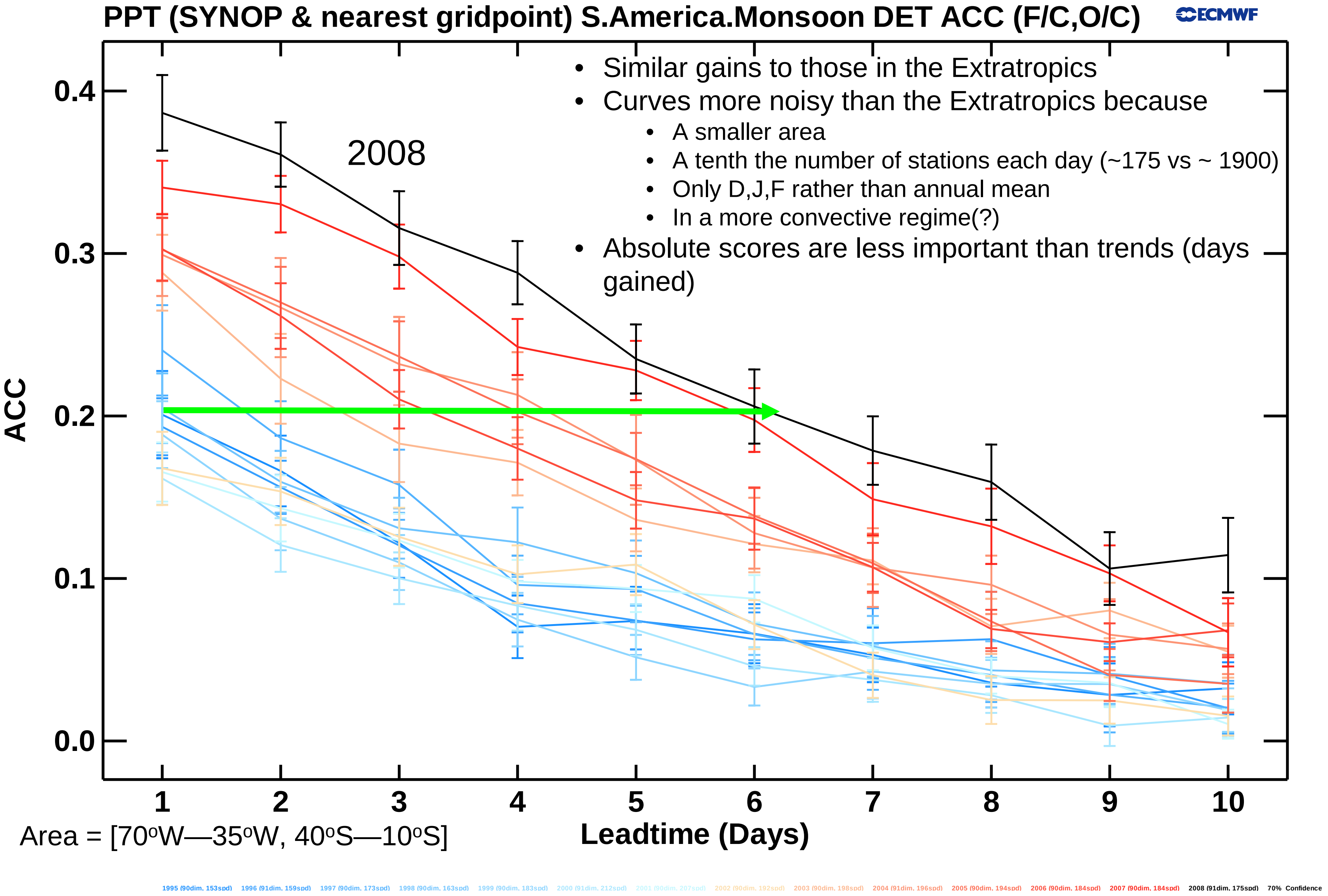

Tropical-mean oceanic TCWV (kg/(m*m))
ERA - Int
RSSv6
GEMS
44
42
40
38
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005


Tropical-mean oceanic precipitation rate (mm/day)
ERA - Int
RSSv6
GPCP
GEMS
6
5
4
3
2
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005

Extratropical Deterministic Precipitation Scores

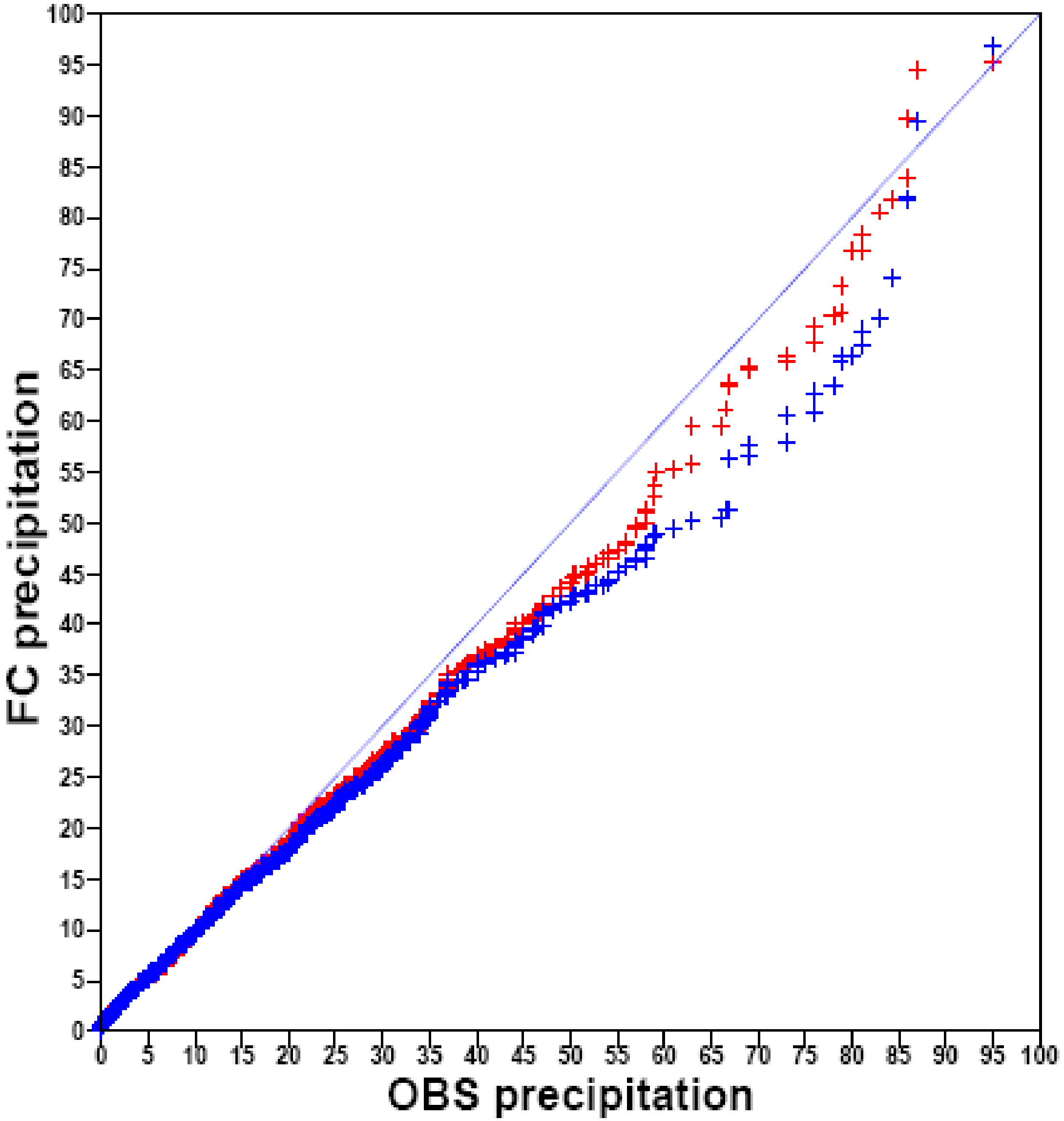


S. American Monsoon (DJF) Det. Precip. Scores



- Similar gains to those in the Extratropics
- Curves more noisy than the Extratropics because
  - A smaller area
  - A tenth the number of stations each day (~175 vs ~ 1900)
  - Only D,J,F rather than annual mean
  - In a more convective regime(?)
- Absolute scores are less important than trends (days gained)

T1279 & T799 versus Obs precipitation Europe



T1279

T799

from 36h forecast winter

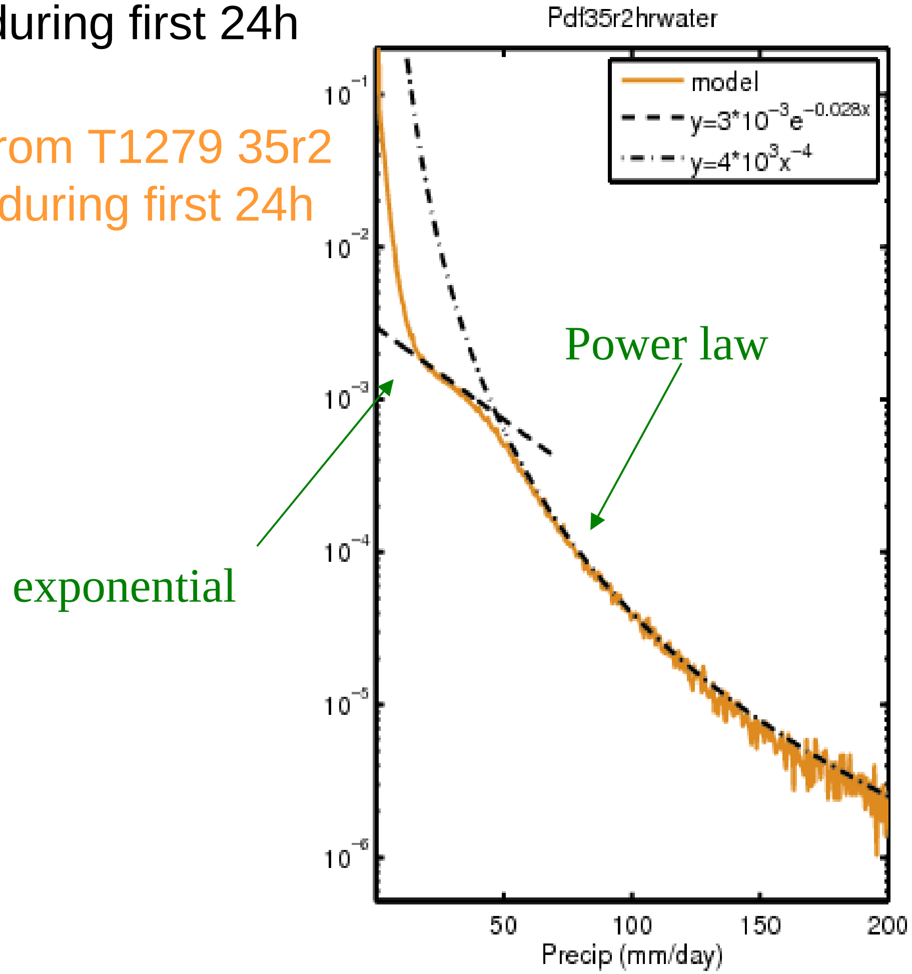
High resolution improves on high precipitation amounts

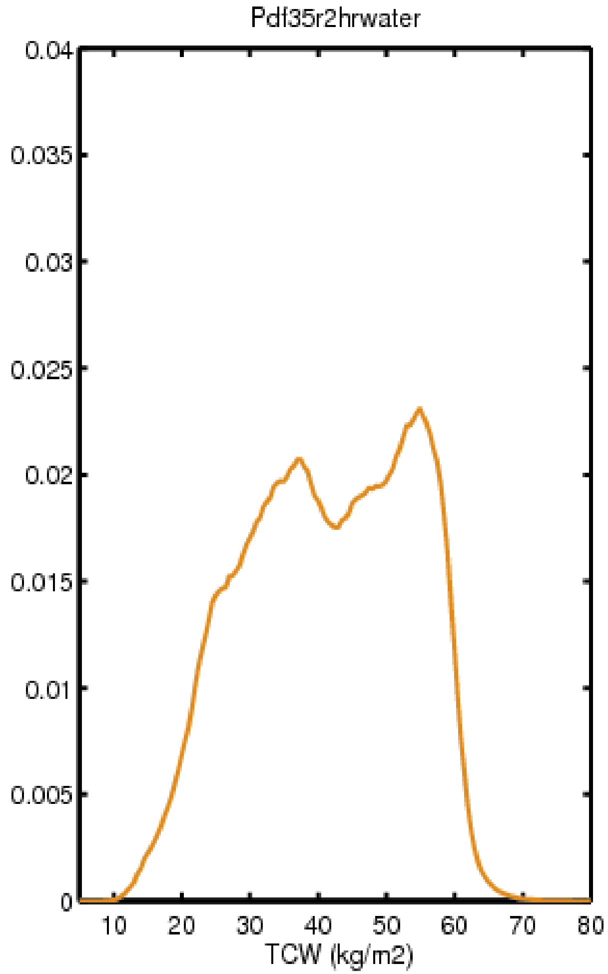
Pdfs of instantanous Precip fluxes and TCW in Tropics

together with A. Geer

from T799 33r1
during first 24h

from T1279 35r2
during first 24h



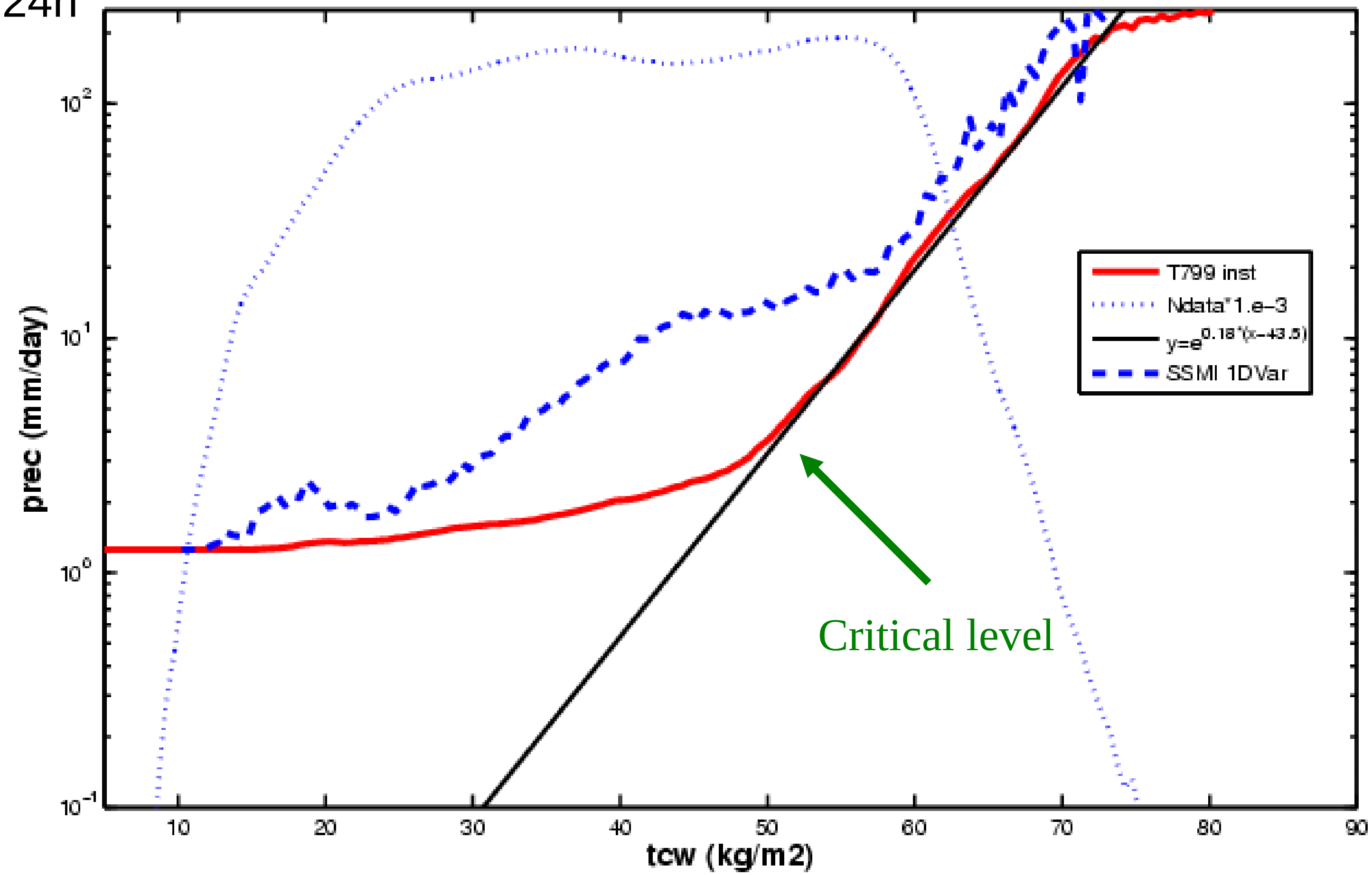


SSMI is from 1D-Var, but underestimates high rain rates (high TCW) as columns where more than 1/3 of precip is snow have been discarded

Mean Precip versus TCW from 2D Pdf

together with A. Geer

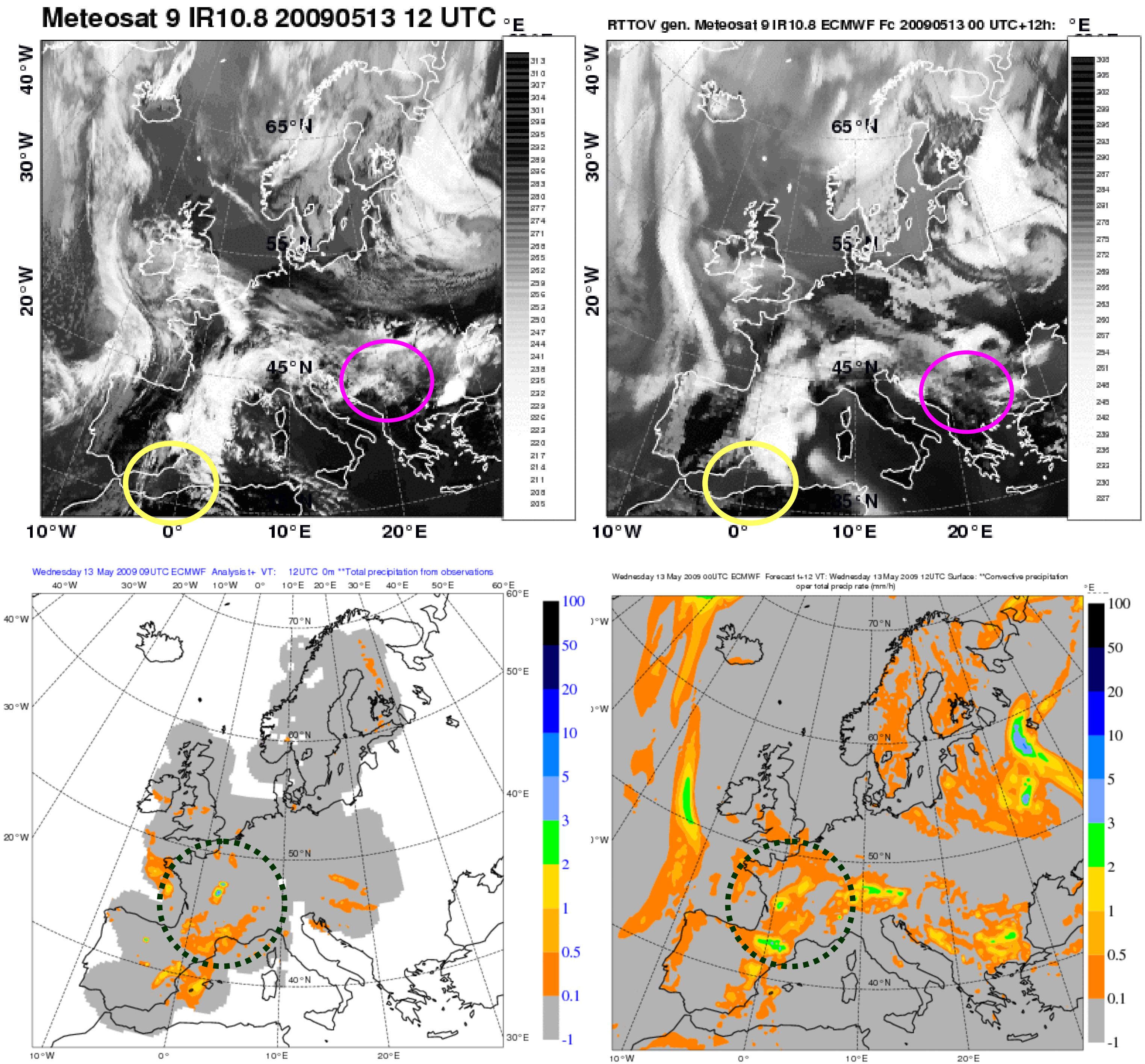
from T799 33r1
during first 24h



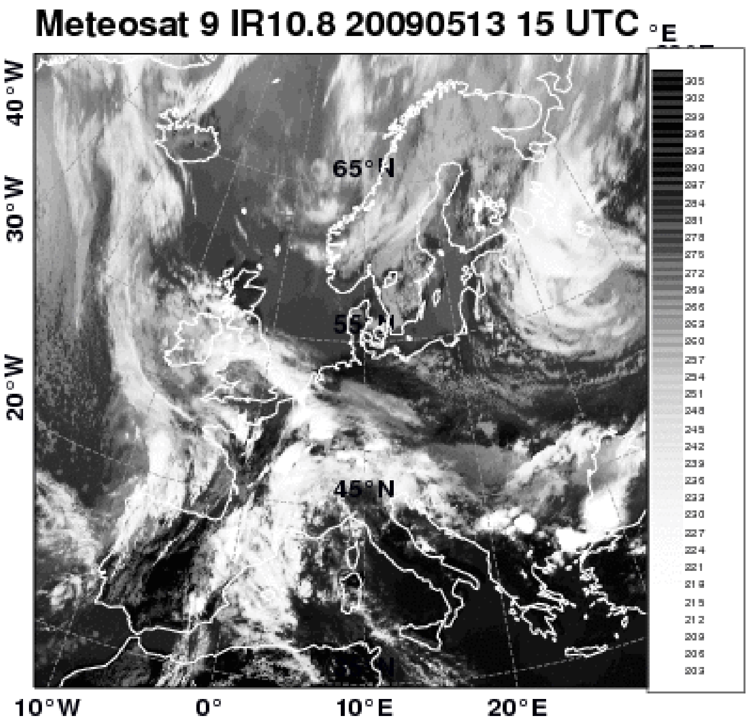
SSMI is from 1D-Var, but underestimates high rain rates (high TCW) as columns where more than 1/3 of precip is snow have been discarded

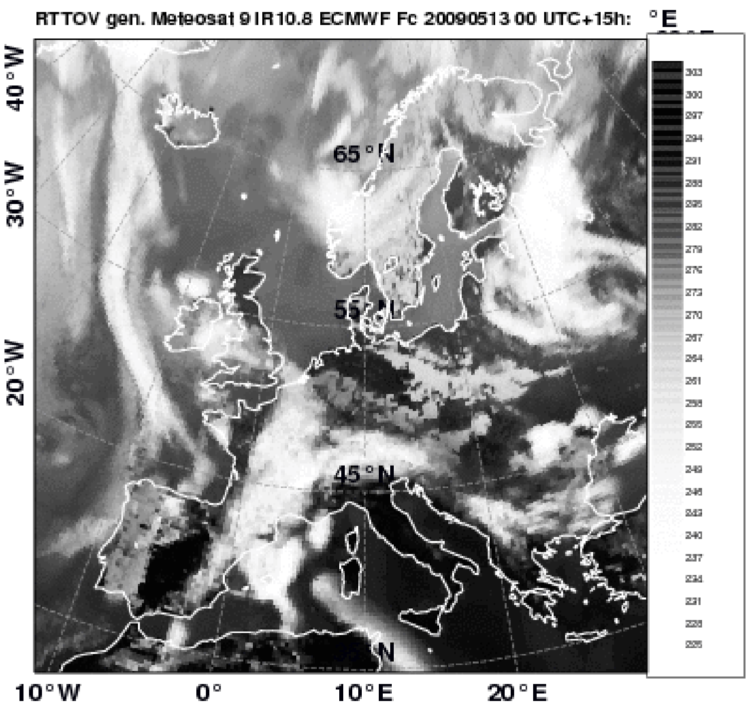
Real case study (random) comparing 3 hourly model cloud (radiation), and precipitation (nearly all of convective type!) with Meteosat and OPERA radar dataset

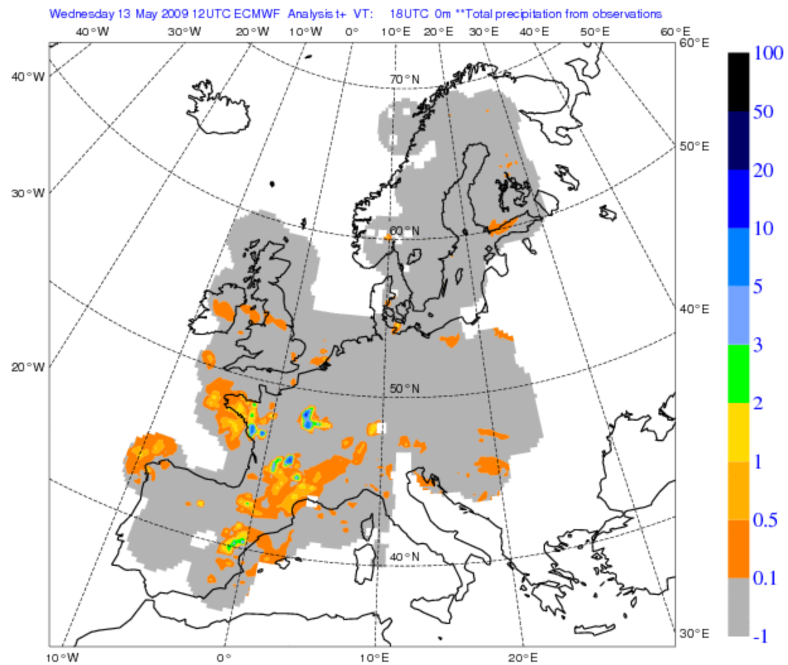
- Can operational model handle convective (extreme) events ?
- Quality issue with dataset
- Preparation for assimilation (Philippe Lopez), 2009/10 together with or first NEXRAD



Meteosat 9 IR10.8 20090513 12 UTC
RTTOV gen. Meteosat 9 IR10.8 ECMWF Fc 20090513 00 UTC+12h:
65°N
55°N
45°N
35°N
40°W
30°W
20°W
10°W
0°
10°E
20°E
Wednesday 13 May 2009 09UTC ECMWF Analysis t+ VT: 12UTC 0m **Total precipitation from observations
Wednesday 13 May 2009 00UTC ECMWF Forecast t+12 VT: Wednesday 13 May 2009 12UTC Surface: **Convective precipitation
oper total precip rate (mm/h)
70°N
60°N
50°N
40°N
100
50
20
10
5
3
2
1
0.5
0.1
-1


Meteosat 9 IR10.8 20090513 15 UTC
65°N
55°N
45°N
40°W
30°W
20°W
10°W
0°
10°E
20°E


RTTOV gen. Meteosat 9 IR10.8 ECMWF Fc 20090513 00 UTC+15h:
65°N
55°N
45°N
40°W
30°W
20°W
10°W
0°
10°E
20°E


Wednesday 13 May 2009 12UTC ECMWF Analysis t+ VT: 18UTC 0m **Total precipitation from observations
70°N
60°N
50°N
40°N
100
50
20
10
5
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2
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0.5
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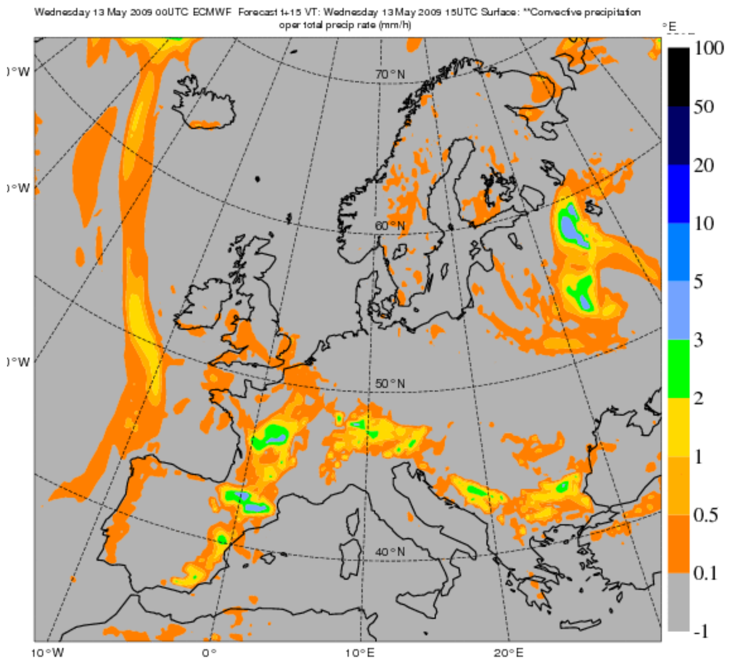
-1


Wednesday 13 May 2009 00UTC ECMWF Forecast t+15 VT: Wednesday 13 May 2009 15UTC Surface: **Convective precipitation
oper total precip rate (mm/h)
70°N
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50°N
40°N
100
50
20
10
5
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2
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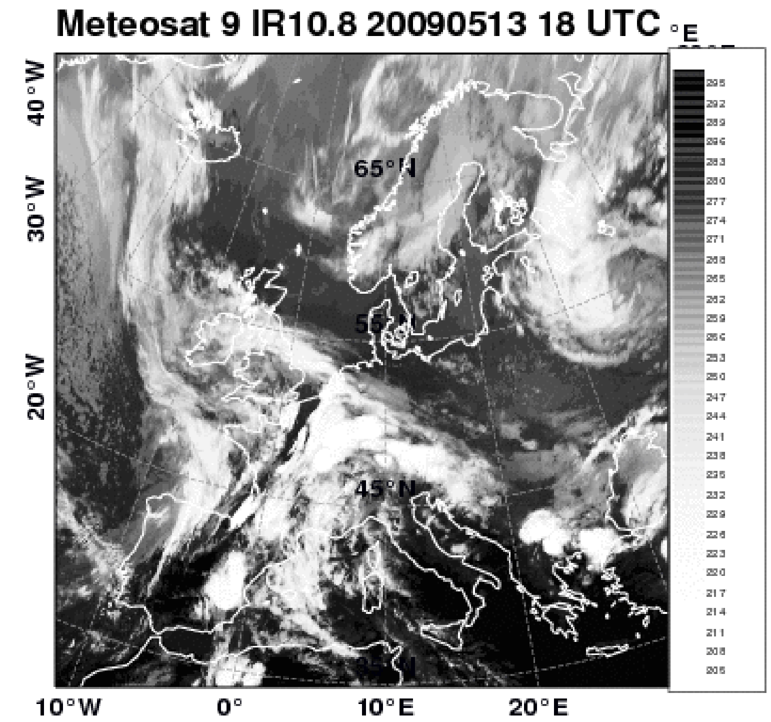
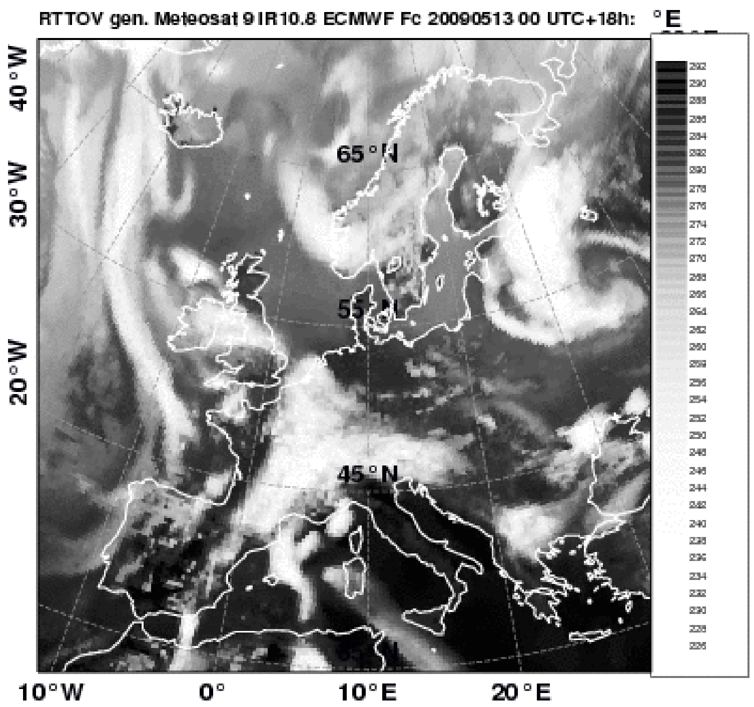
0.5
0.1
-1


Meteosat 9 IR10.8 20090513 18 UTC
65°N
55°N
45°N
40°W
30°W
20°W
10°W
0°
10°E
20°E


RTTOV gen. Meteosat 9 IR10.8 ECMWF Fc 20090513 00 UTC+18h:
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55°N
45°N
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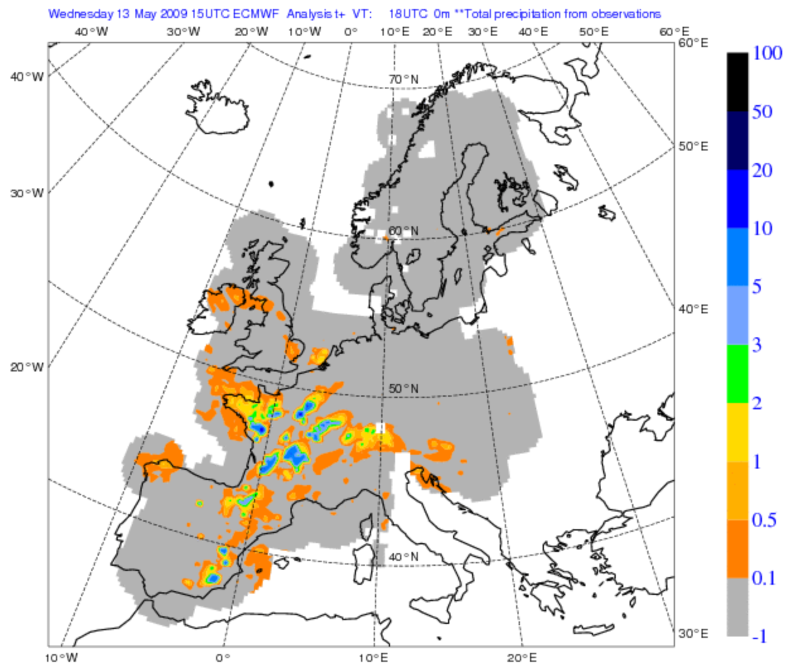
30°W
20°W
10°W
0°
10°E
20°E


Wednesday 13 May 2009 15UTC ECMWF Analysis t+ VT: 18UTC 0m **Total precipitation from observations
70°N
60°N
50°N
40°N
100
50
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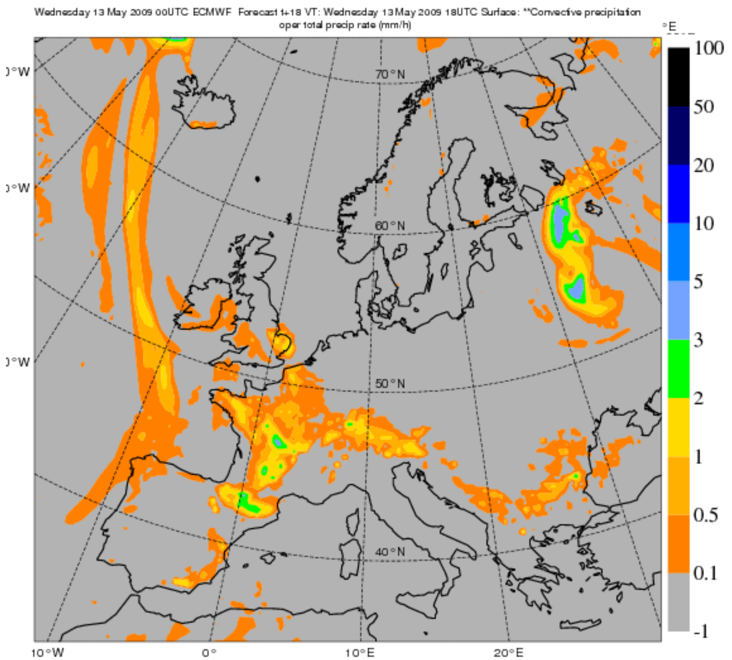
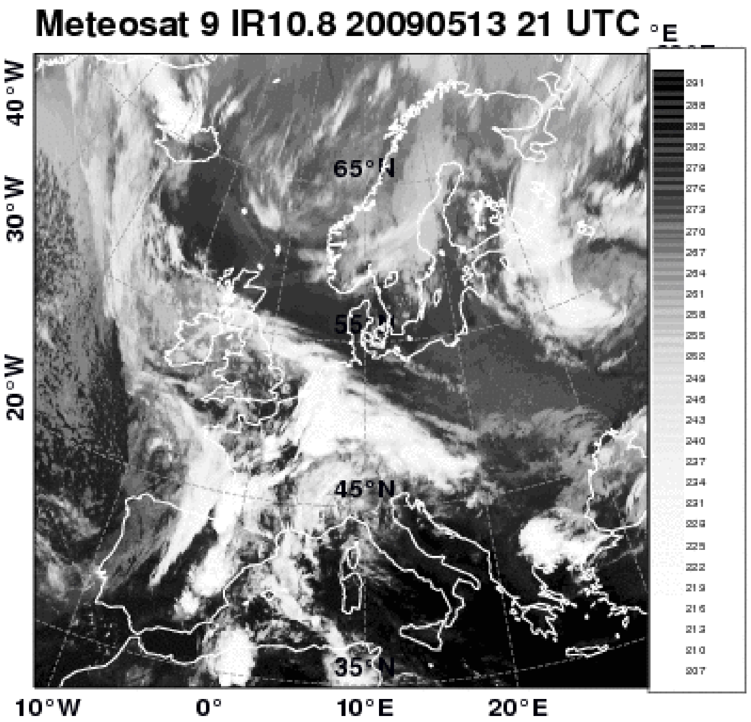
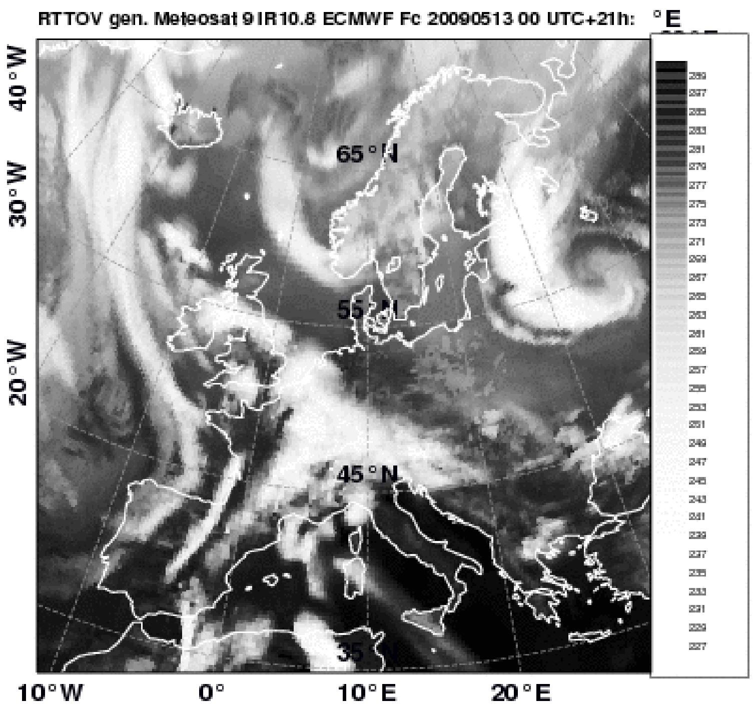
0.5
0.1
-1


Wednesday 13 May 2009 00UTC ECMWF Forecast t+18 VT: Wednesday 13 May 2009 18UTC Surface: **Convective precipitation
oper total precip rate (mm/h)
70°N
60°N
50°N
40°N
100
50
20
10
5
3
2
1
0.5
0.1
-1


Meteosat 9 IR10.8 20090513 21 UTC
65°N
55°N
45°N
35°N
10°W
0°
10°E
20°E
40°W
30°W
20°W


RTTOV gen. Meteosat 9 IR10.8 ECMWF Fc 20090513 00 UTC+21h:
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55°N
45°N
10°W
0°
10°E
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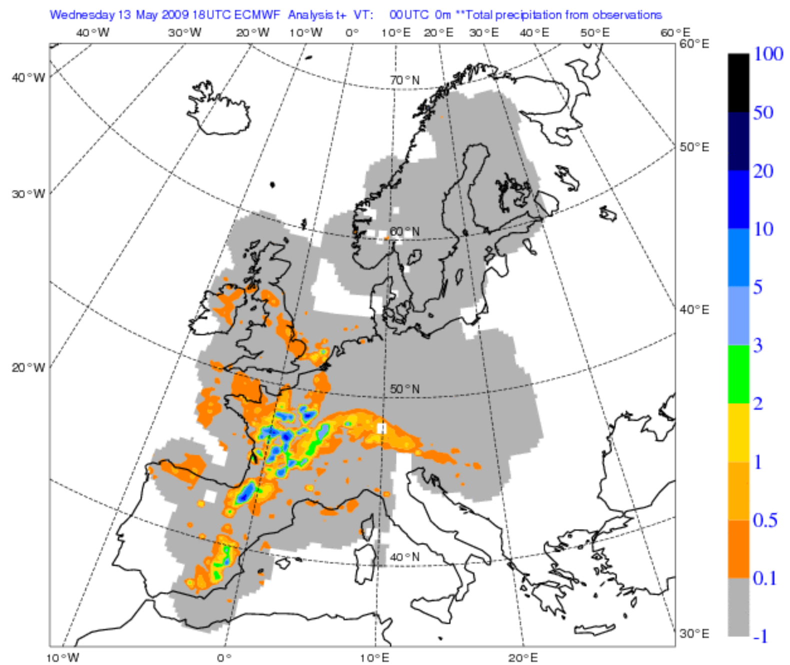
40°W
30°W
20°W


Wednesday 13 May 2009 18UTC ECMWF Analysis t+ VT: 00UTC 0m **Total precipitation from observations
70°N
60°N
50°N
40°N
100
50
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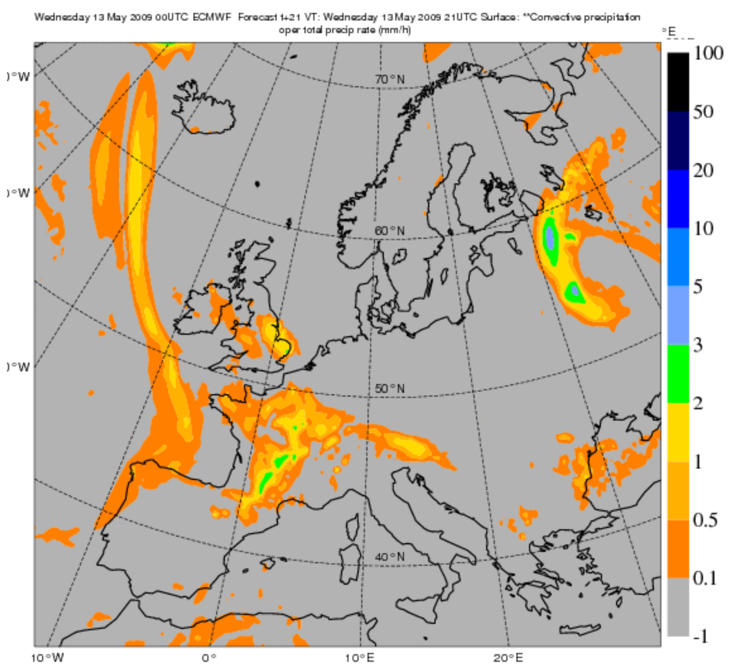
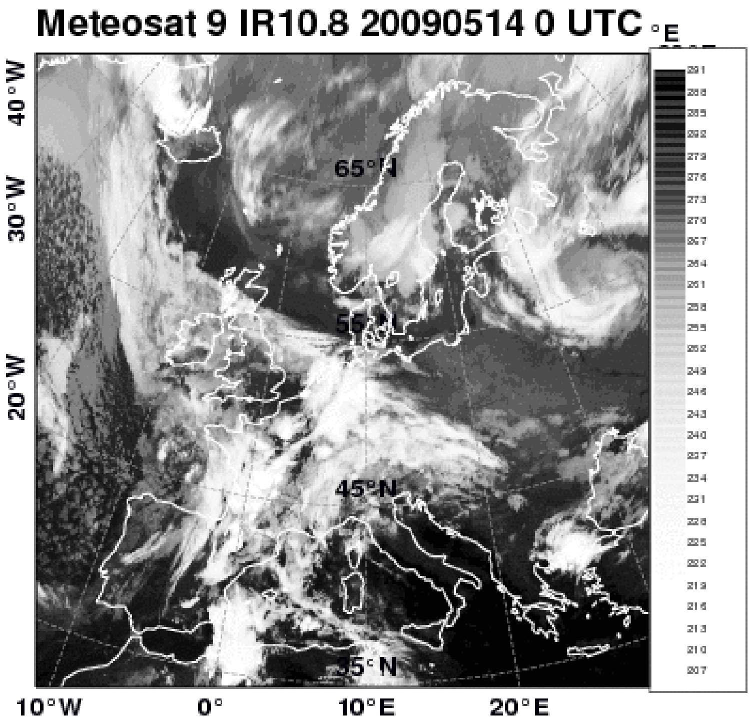
10
5
3
2
1
0.5
0.1
-1


Wednesday 13 May 2009 00UTC ECMWF Forecast t+21 VT: Wednesday 13 May 2009 21UTC Surface: **Convective precipitation
oper total precip rate (mm/h)
70°N
60°N
50°N
40°N
100
50
20
10
5
3
2
1
0.5
0.1
-1


Meteosat 9 IR10.8 20090514 0 UTC
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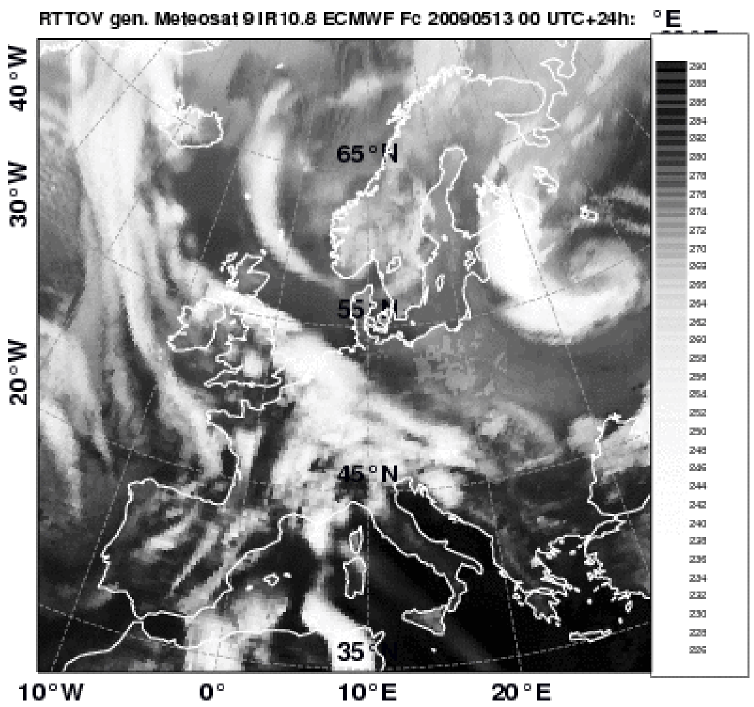
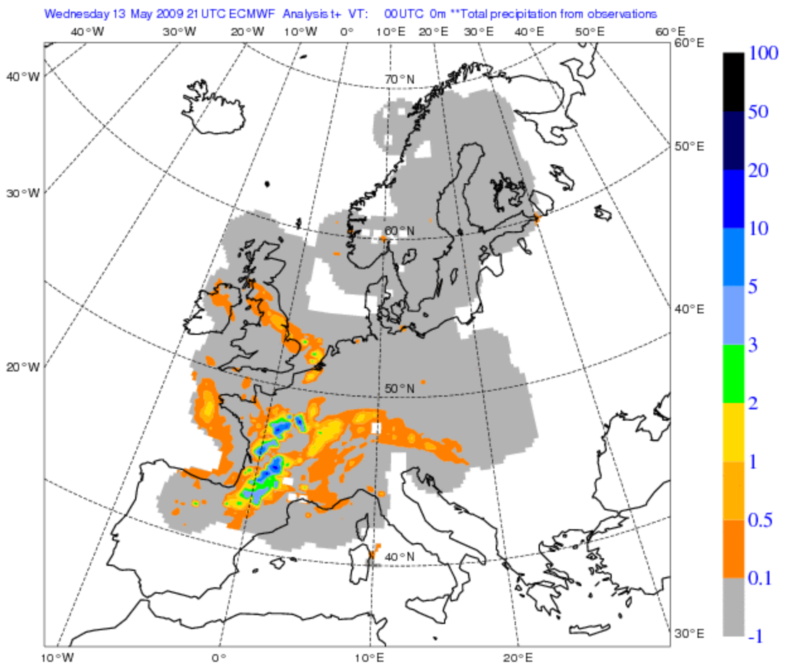
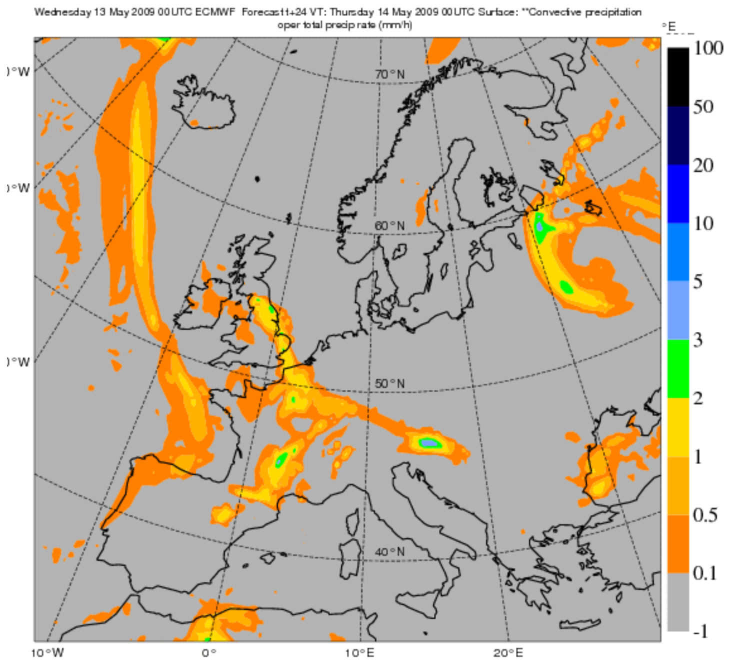
55°N
45°N
35°N
40°W
30°W
20°W
10°W
0°
10°E
20°E

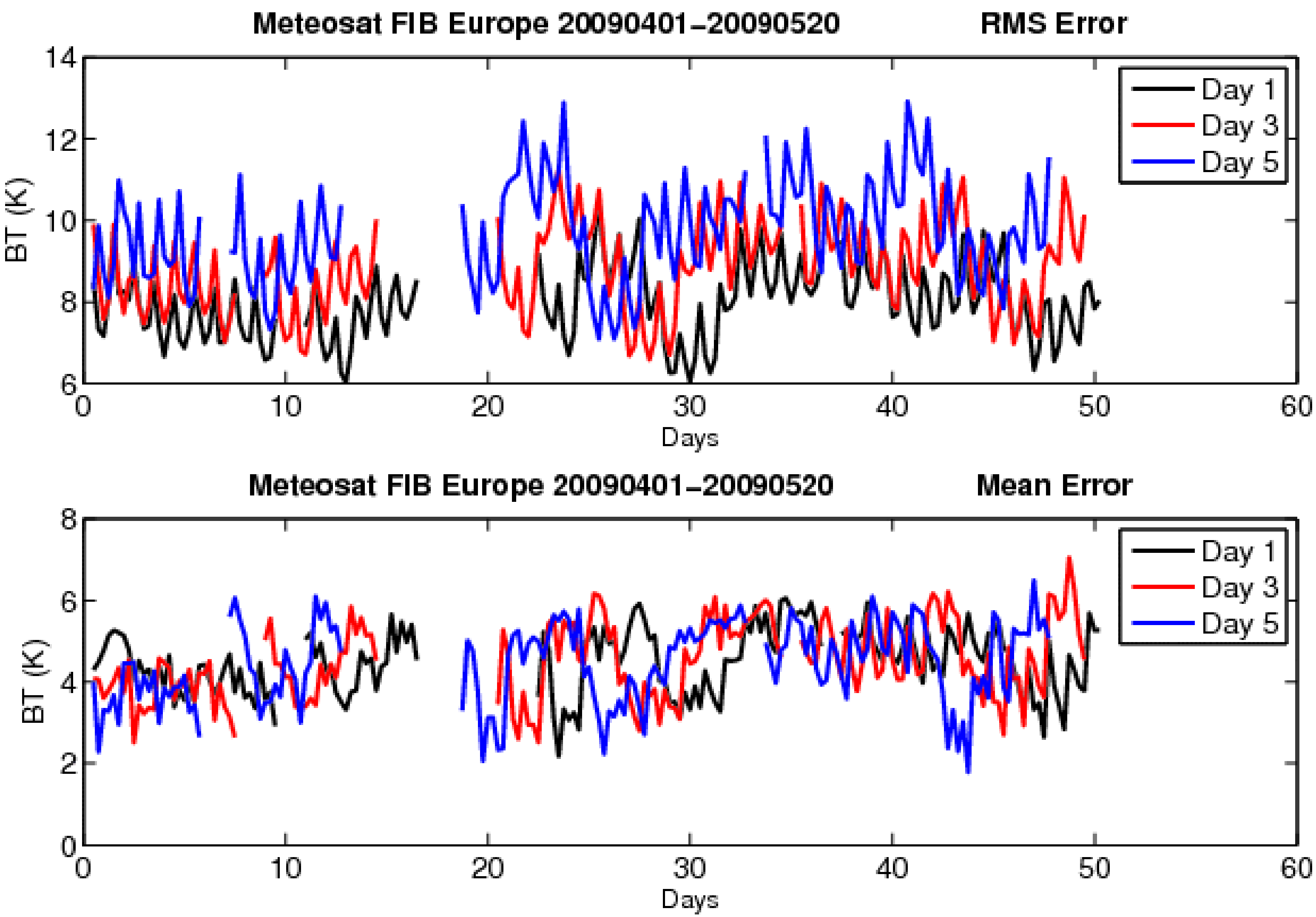

RTTOV gen. Meteosat 9 IR10.8 ECMWF Fc 20090513 00 UTC+24h:
65°N
55°N
45°N
35
40°W
30°W
20°W
10°W
0°
10°E
20°E


Wednesday 13 May 2009 21 UTC ECMWF Analysis t+ VT: 00UTC 0m **Total precipitation from observations
70°N
60°N
50°N
40°N
100
50
20
10
5
3
2
1
0.5
0.1
-1

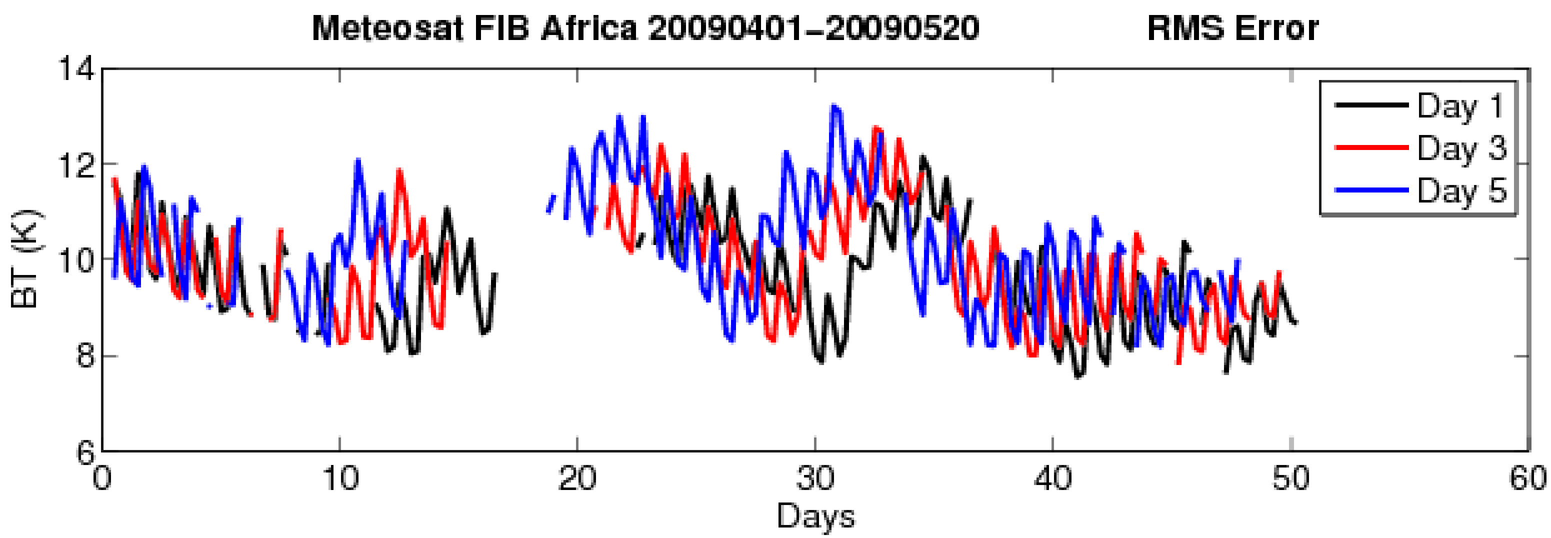

Wednesday 13 May 2009 00UTC ECMWF Forecast t+24 VT: Thursday 14 May 2009 00UTC Surface: **Convective precipitation
oper total precip rate (mm/h)
70°N
60°N
50°N
40°N
100
50
20
10
5
3
2
1
0.5
0.1
-1

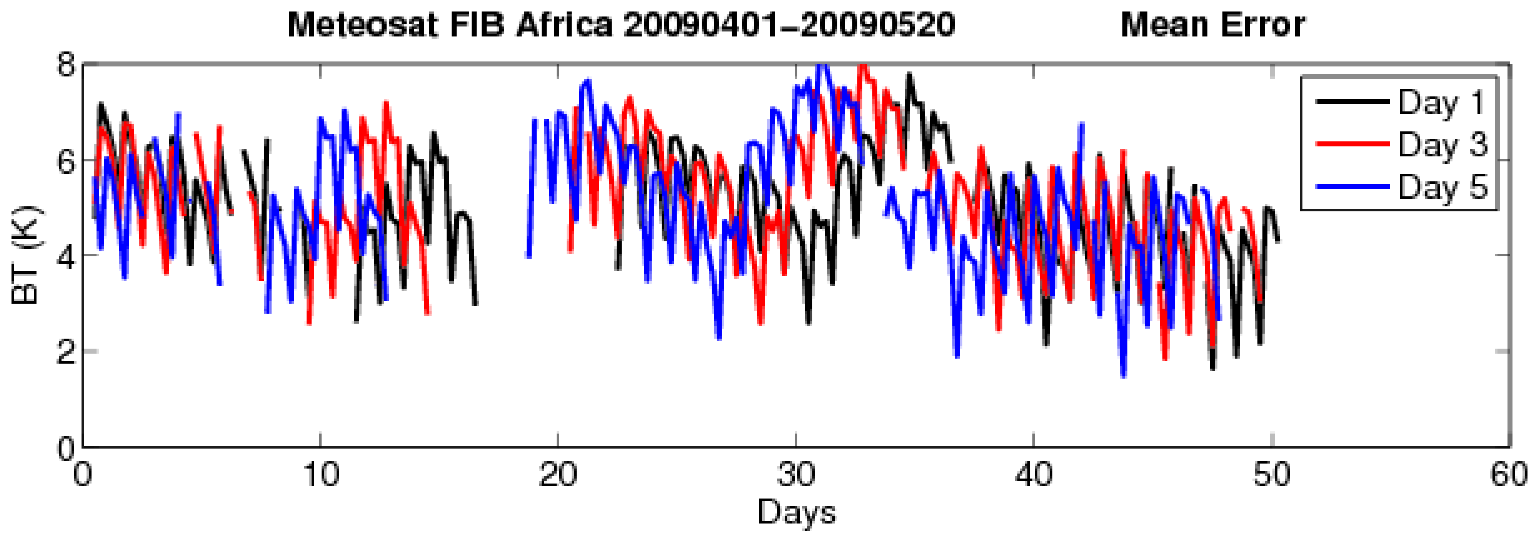
- Most important is to handle large-scale forcing right through analysis and forecast system
- some randomness in convective systems forming can never be forecast always precisely…. EPS & ensemble data assimilation
- Model can handle formation and advection of mesoscale convective systems
- Cannot produce the local high precipitation intensities (typically 10 mm/h is already a lot for purely convective precip (non-saturated column))

Satellite verification Meteosat IR Europe 6h

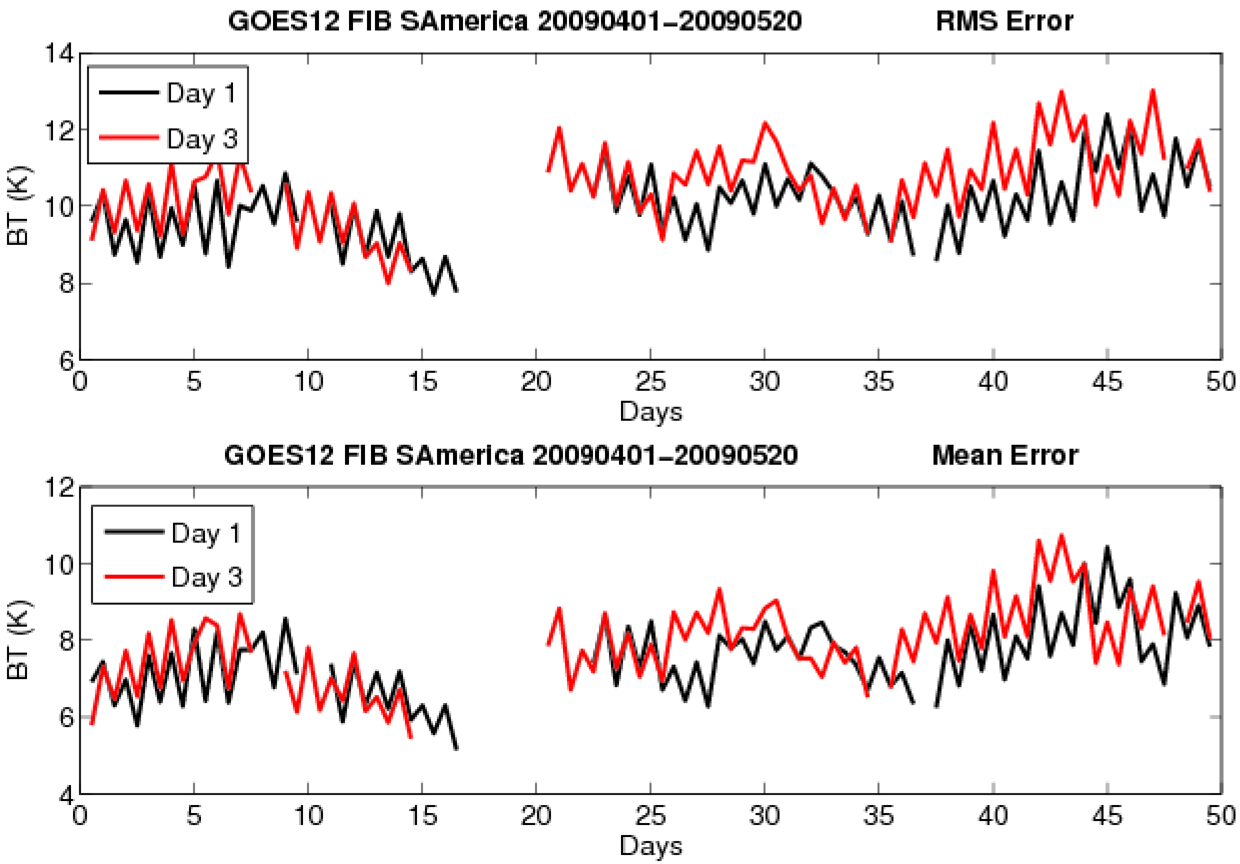


Satellite verification Meteosat IR Africa 6h





Satellite verification GOES12 IR SAmerica 12h

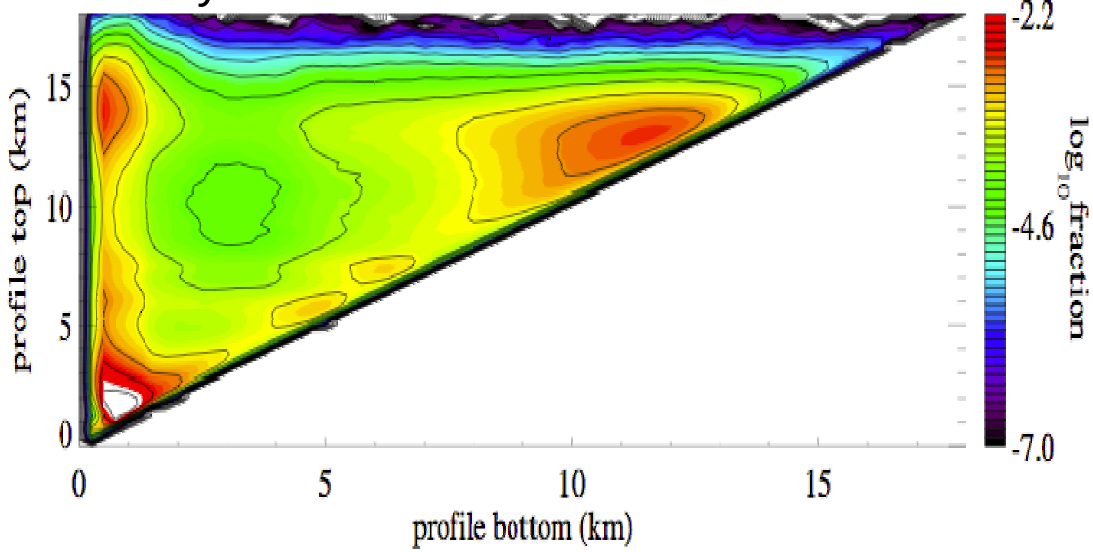


Aim

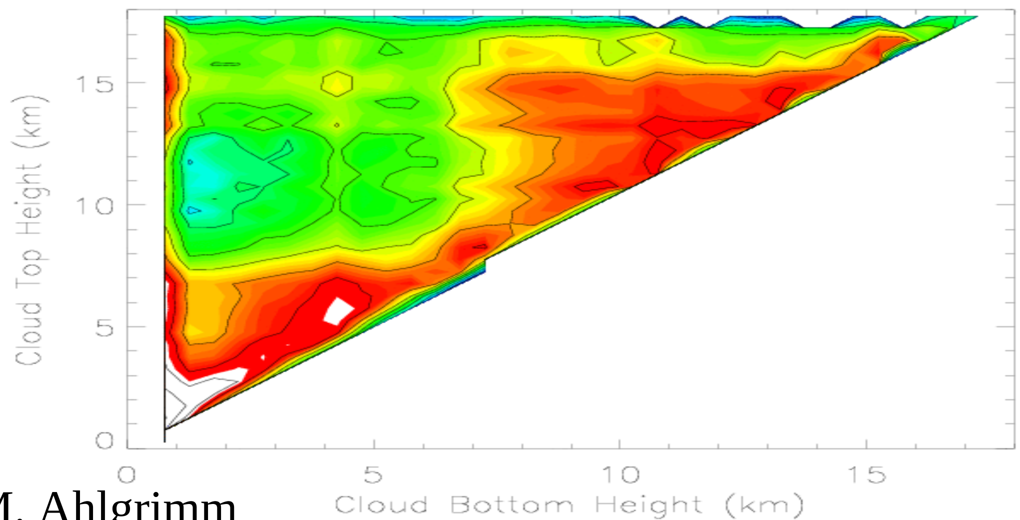
- Identify biases (cold cloud tops, optical thickness)
- Diurnal cycle
- Official forecast product from June 2009

Cloud Verification
Tropical Cloud Height and Depth

1 year CloudSat data 20°S-20°N



Snapshot of ECMWF model 06 Aug 2008 (20°S-20°N)



R. Forbes + M. Ahlgrimm

Tropical Cyclones

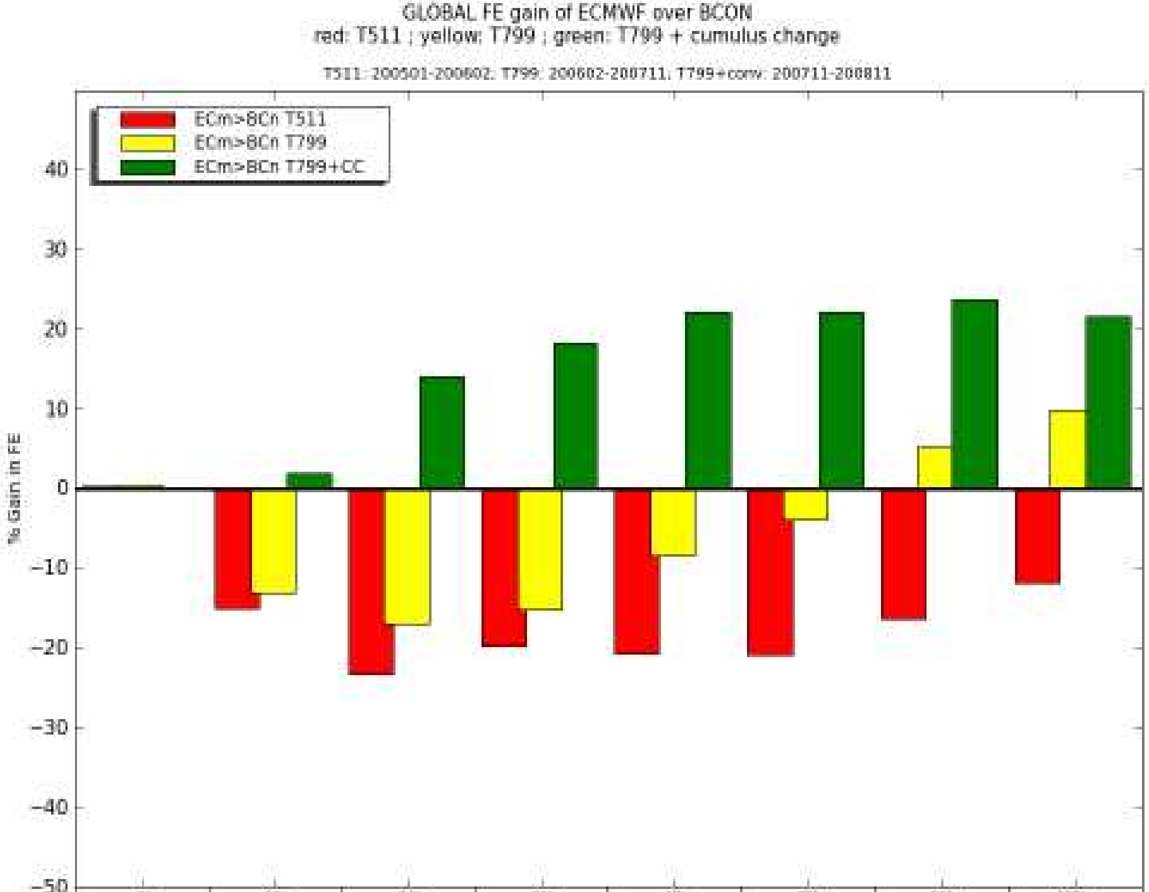
Physics and Resolution

Quality of IFS tropical cyclone forecasts versus model consens:

T511

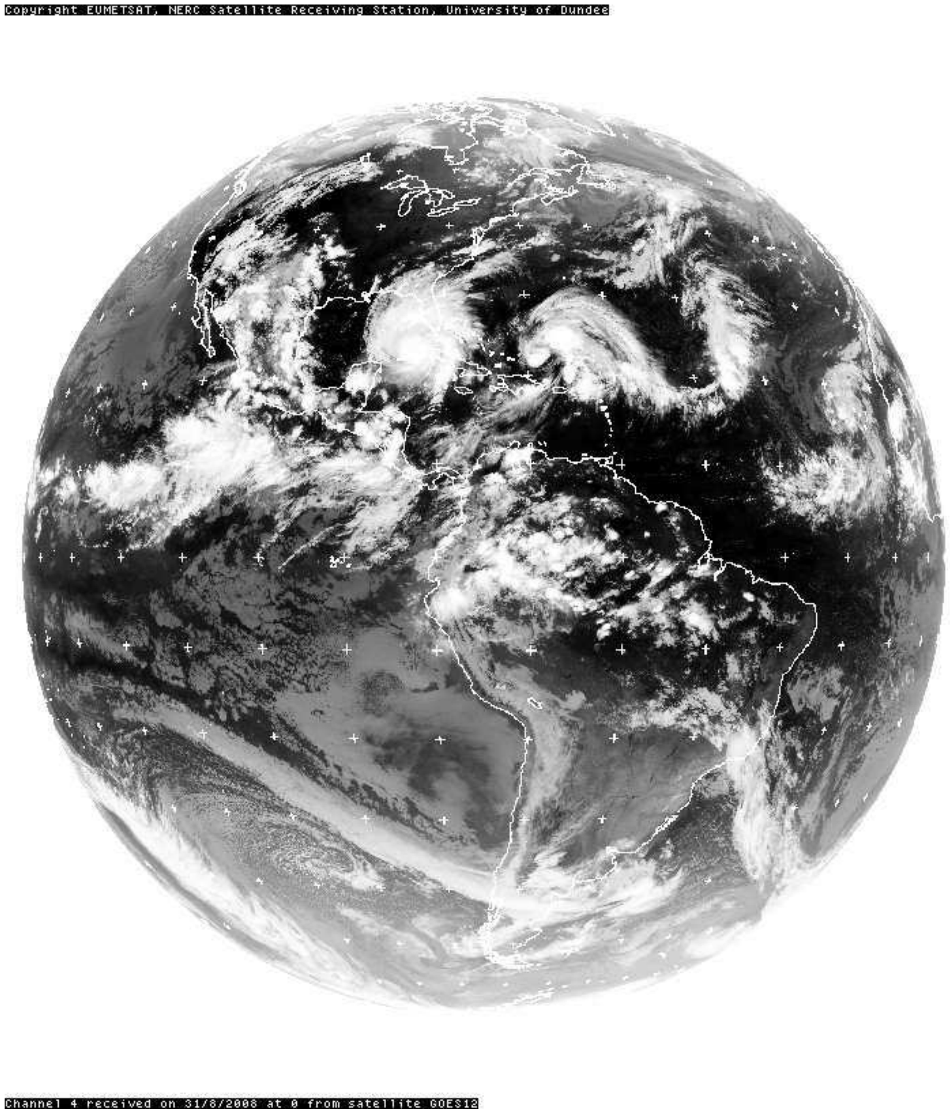
T799

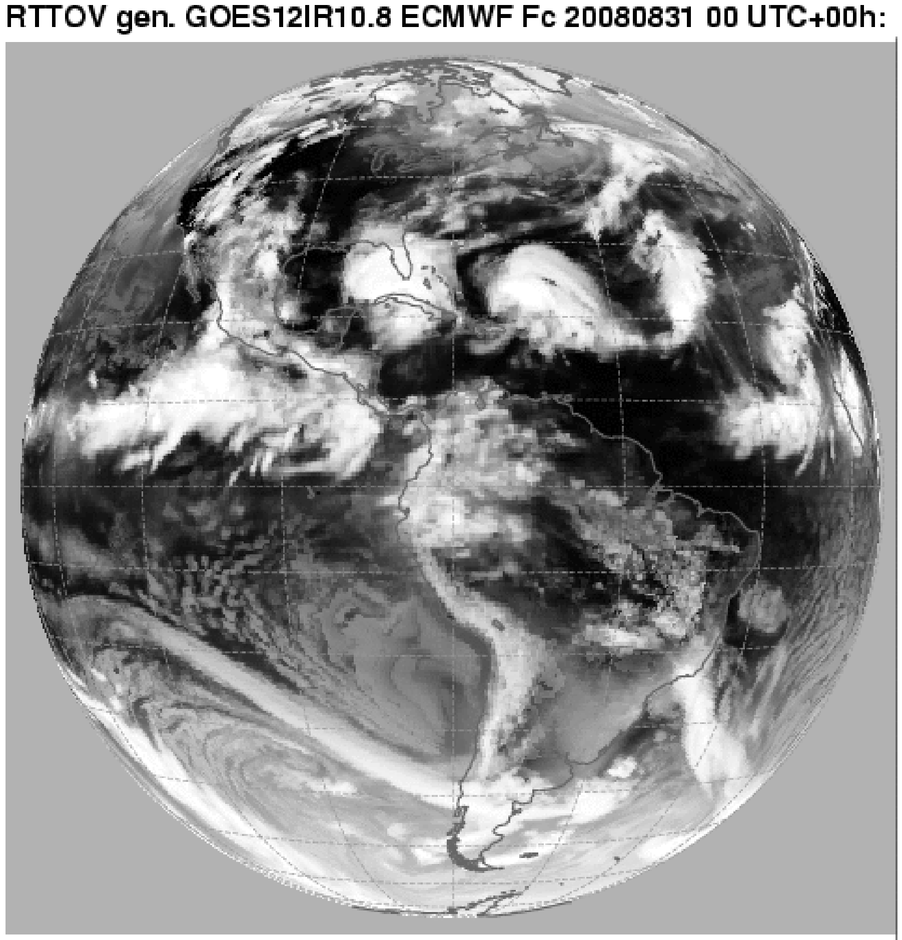
Physics



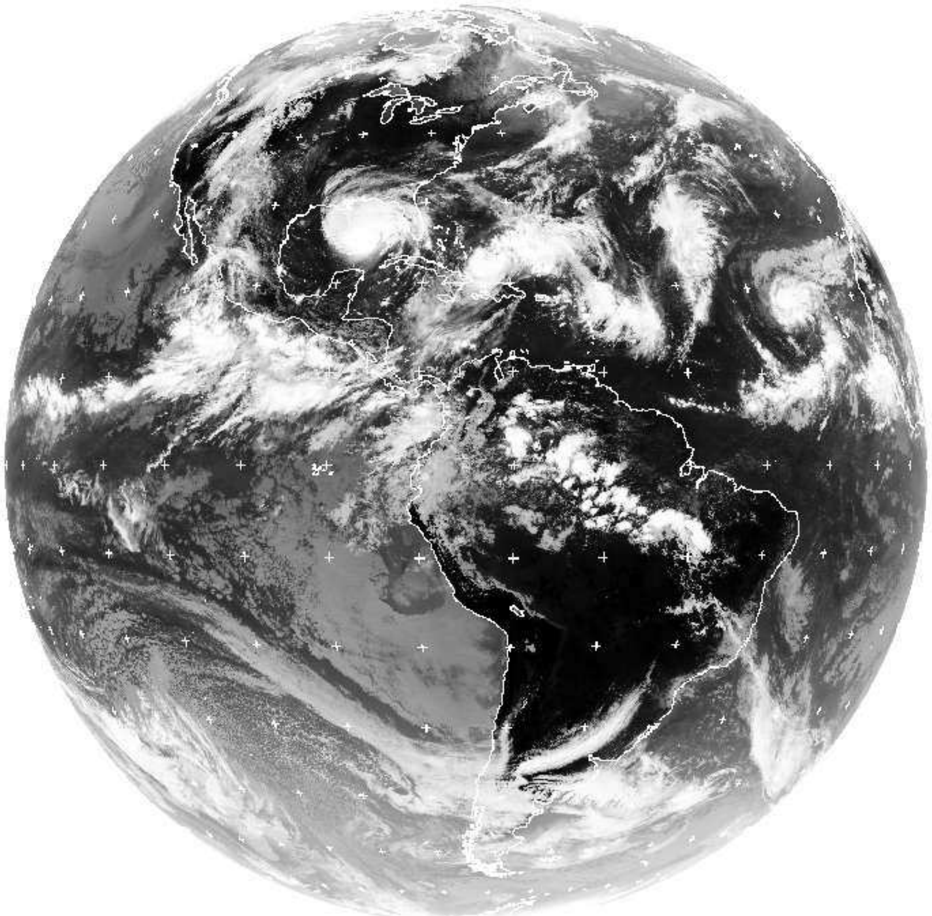
	0h	12h	24h	36h	48h	72h	96h	120h
[illegible]	0[822]	-15[758]	-23[682]	-20[600]	-21[526]	-21[400]	-16[299]	-12[214]
m>BCn T799	0[994]	-13[906]	-17[805]	-15[719]	-8[627]	-4[460]	5[321]	10[213]
m>BCn T799+CC	-0[824]	2[766]	14[692]	18[618]	22[546]	22[428]	24[315]	22[225]

Fig. 1. % gain or improvement in mean forecast error (FE) of ECMWF v Best/BaslineCONsensus (BCON) for all TCs globally. red - T511 200501-200602; yellow - T799 200602-200711; green - T799 + convection change (200711-200811).



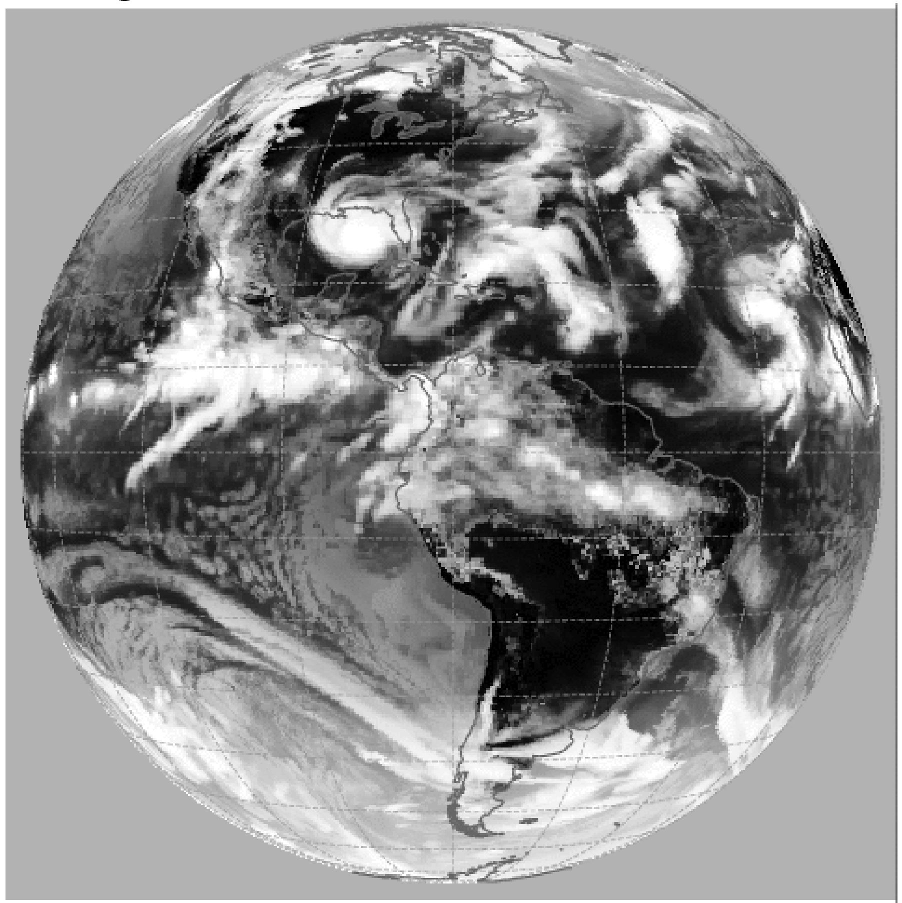


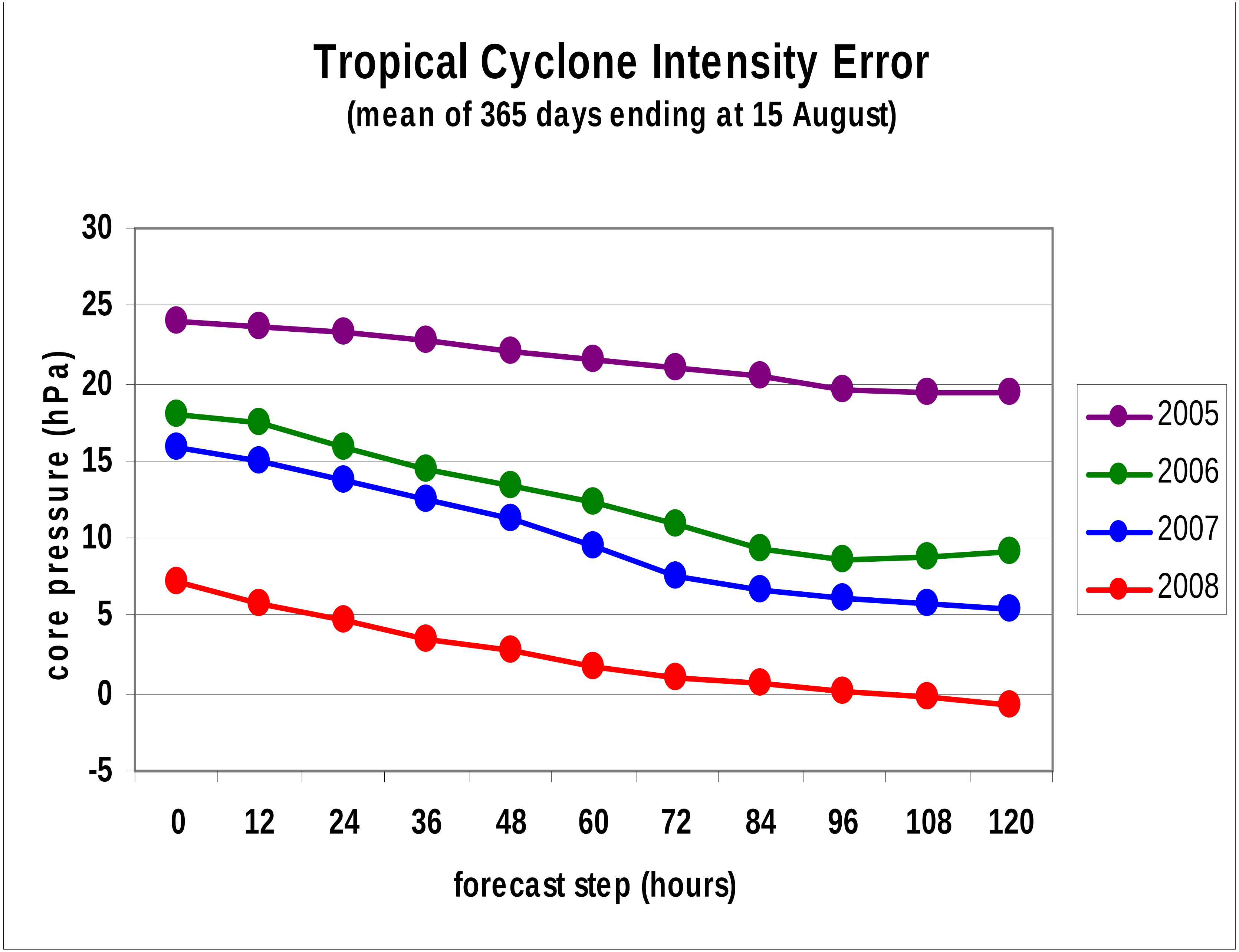
Tropical cyclones still a bit too weak in analysis, but good position



Channel 4 received on 31/8/2008 at 1800 from satellite GOES12

RTTOV gen. GOES12IR10.8 ECMWF Fc 20080831 00 UTC+18h:





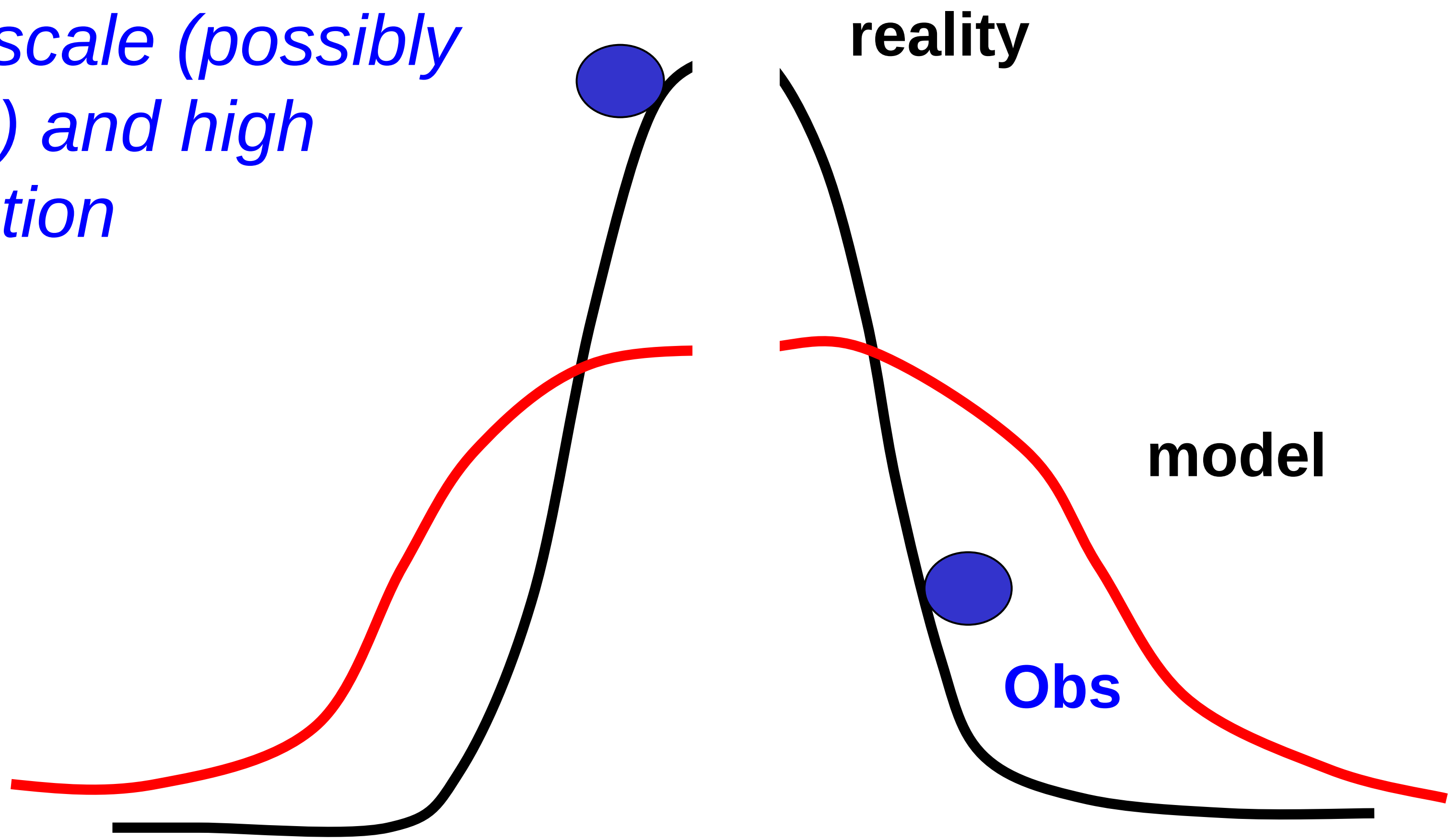
2006 Resolution change T511 (40 km) -> T799 (25 km)

2008 Physics change (mainly convection)

Cyclones and data assimilation

Distribution of radial wind field and importance of high resolution inner loop

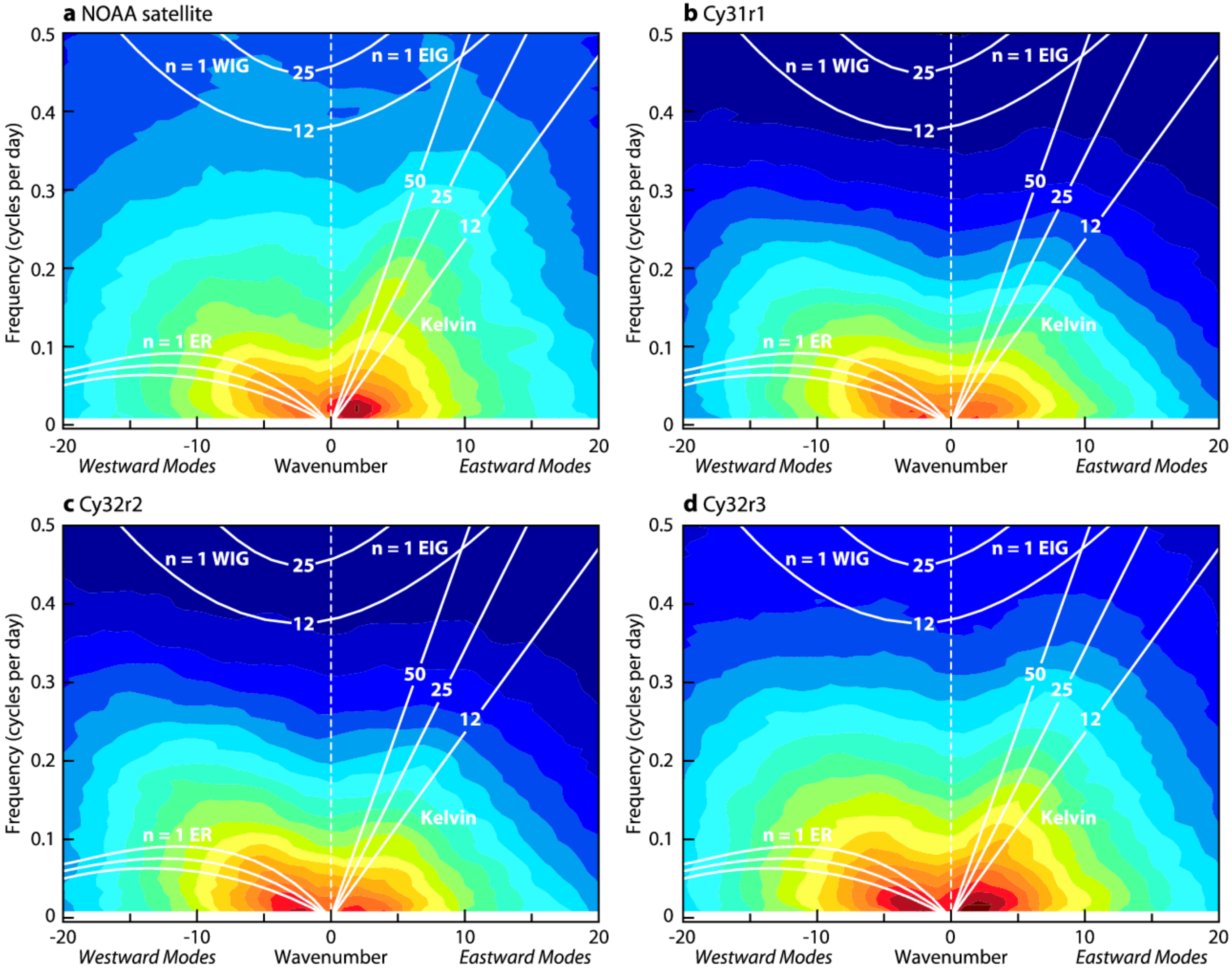
System needs to be large-scale (possibly global) and high resolution



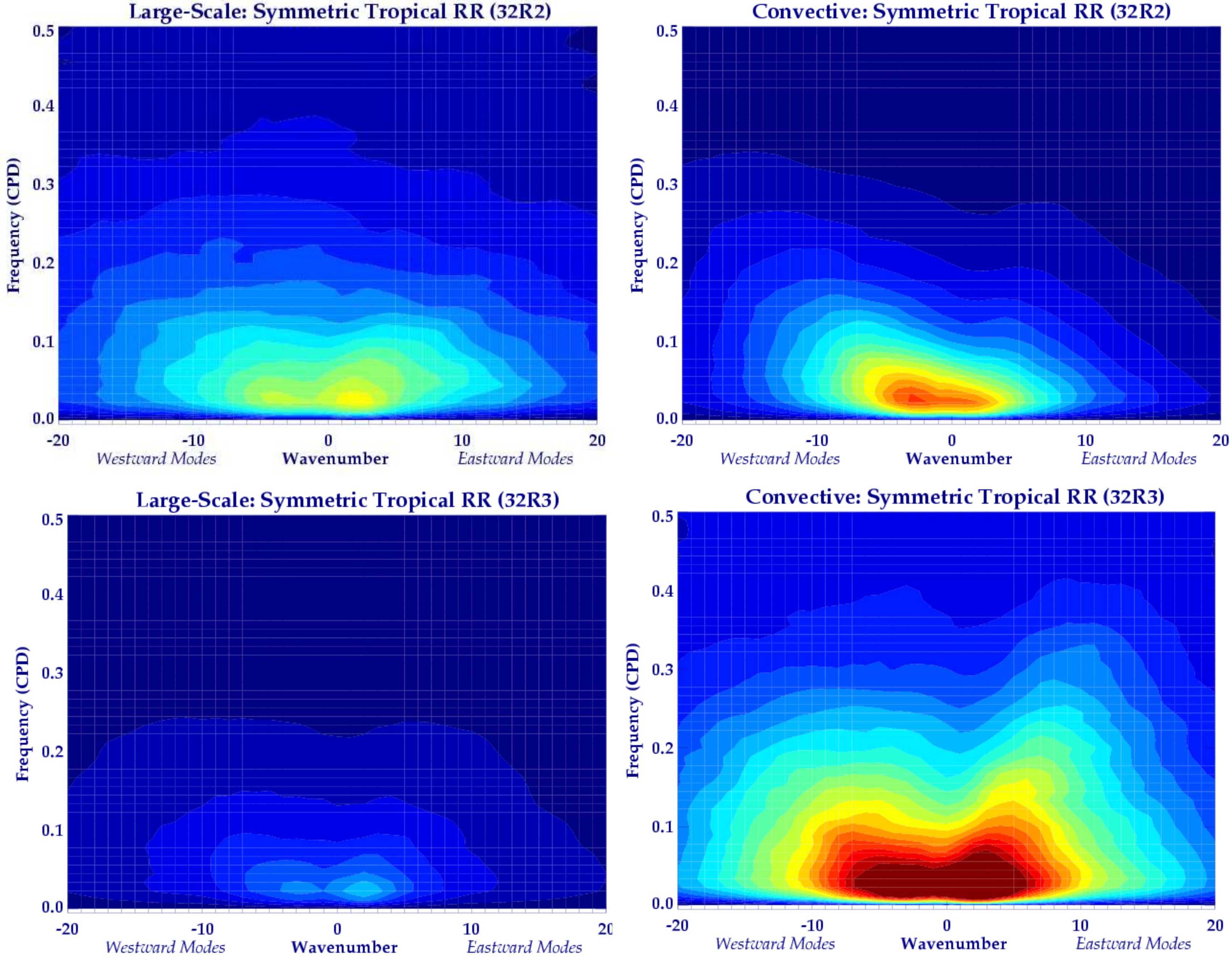
Tropical Waves

MJO

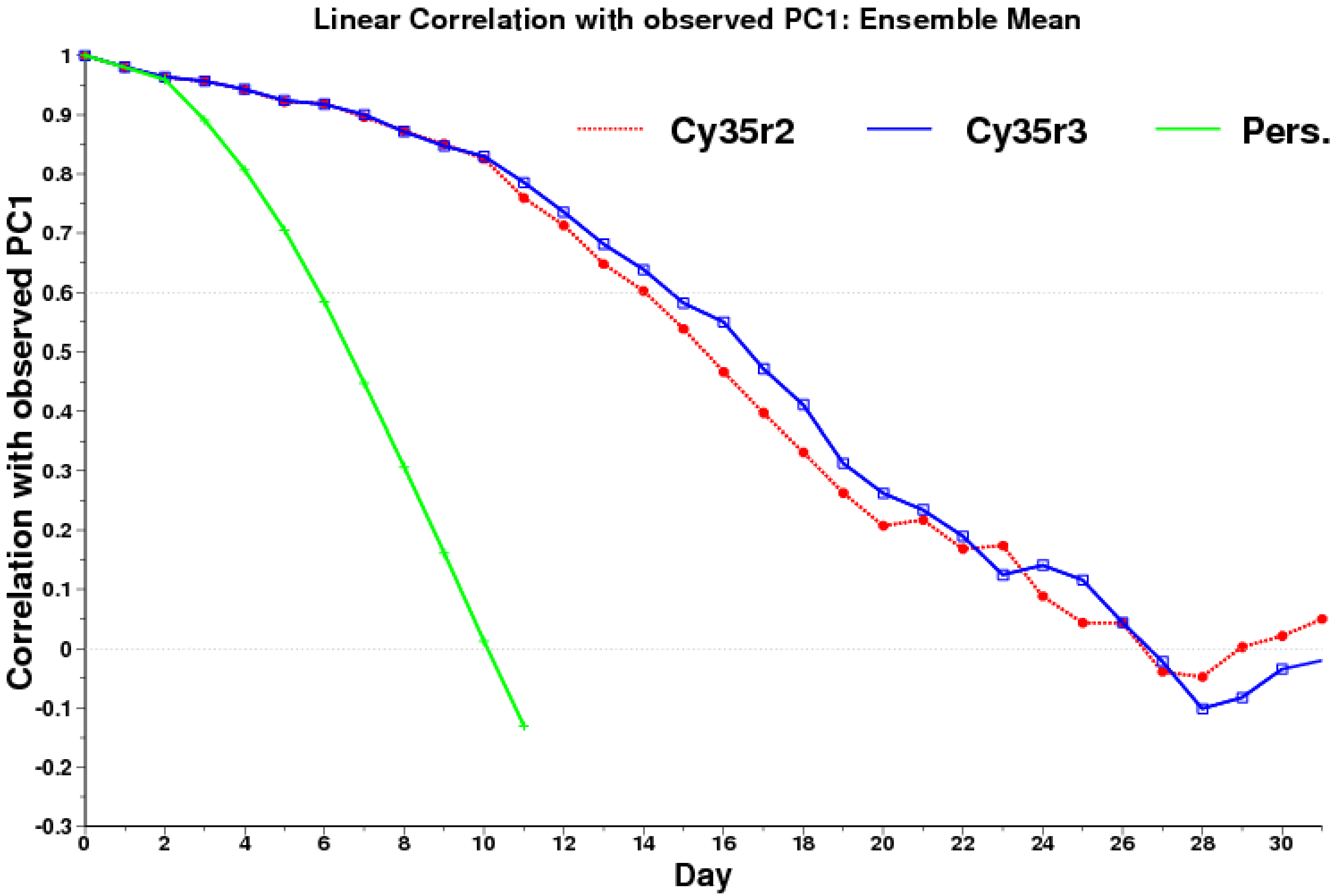
Wavenumber frequency Diagrams of OLR



Wavenumber frequency Diagrams of CP & LSP



How predictible is the MJO currently



Conclusions on MJO

- Very tricky and very sensitive to everything in model
- still not clear what is most important: shape and phase of vertical heating profile, or lateral forcing of Tropics through midlatitude Rossby waves
- important to get first Kelvin waves right, and this with convective, not grid-resolved! Heating/precipitation
- slowly getting better, so far reasonable predictability for 15 days
- but still do not get distinctive spectral peak at 20-60 days for e.g. 850 hPa U, too much power at low periods.

Other possibilities to improve representation of convection

Cellular Automaton

Some prognostic approach

………already in place in ALARO

Cellular Automaton

belongs to the family of self-critical systems, e.g. forest fires, sand pile, game of life etc.

Aim:

- Improve on the MJO
- Improve on the propagation of convection in general

Technique (see more with Lisa):

- Use e.g regular lat/lon grid, play game of life
- Initialize living cells at convective points, propagate and create living cells as function of CAPE using certain rules – include wind speed through probability
- Couple 2D CA field (number of lives) to convection parametrization by perturbing T,q input profiles (+ [living cells] or – [no lives] vertical sine function, amplitude 0.2 K, 2% humidity)

Cellular Automaton Toy Model

together with Martin Steinheimer & Glenn Shutts

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	15	15	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	15	15	15	15	0	0	0	0	0	0	0	0
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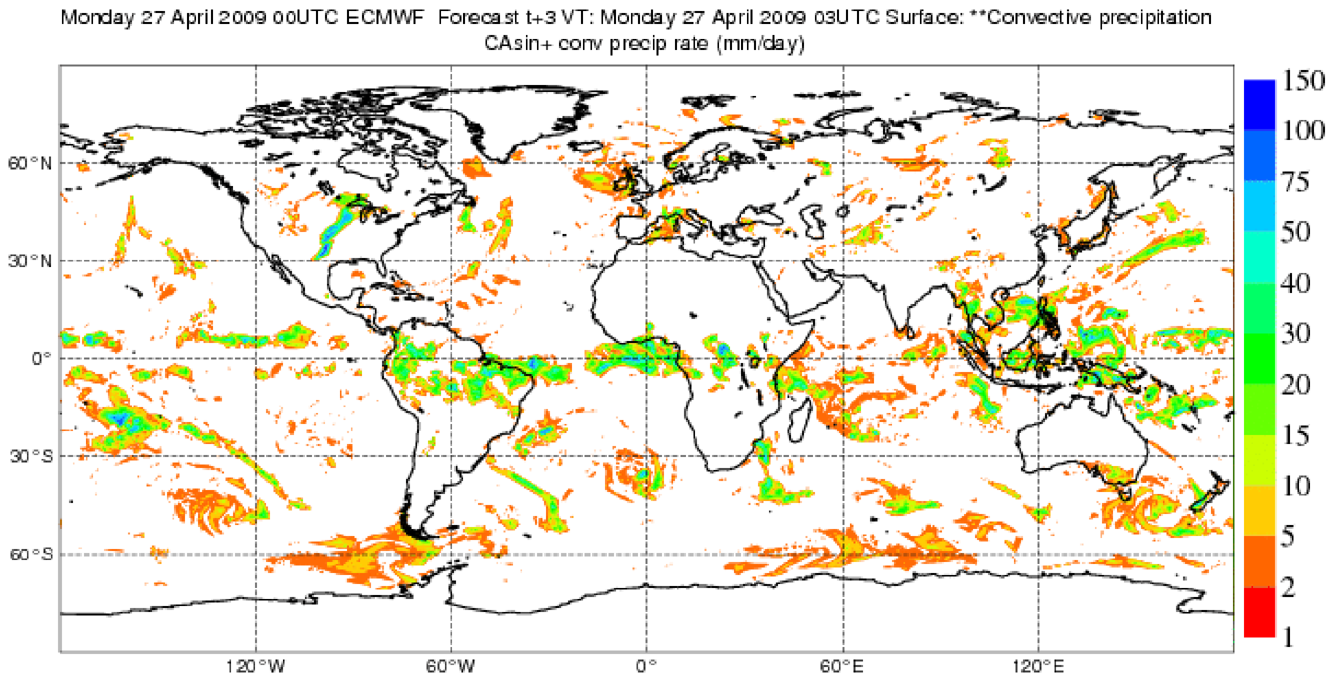
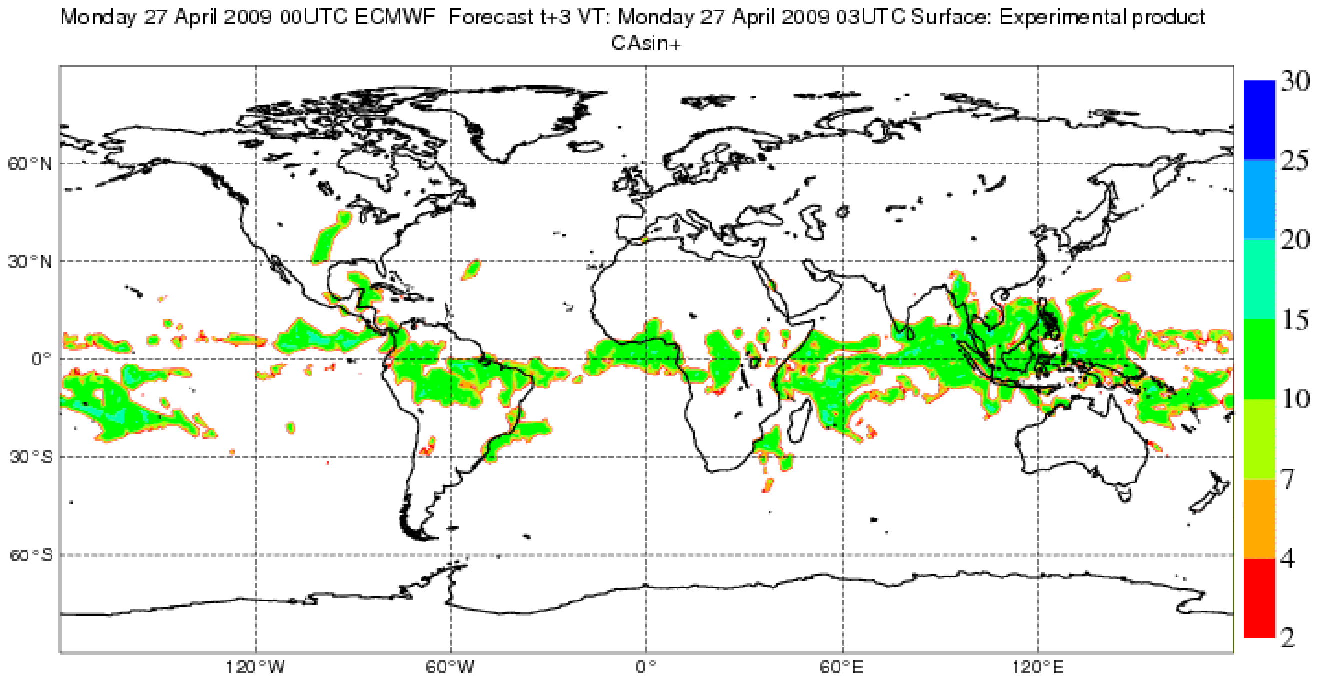
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cellular Automaton in IFS

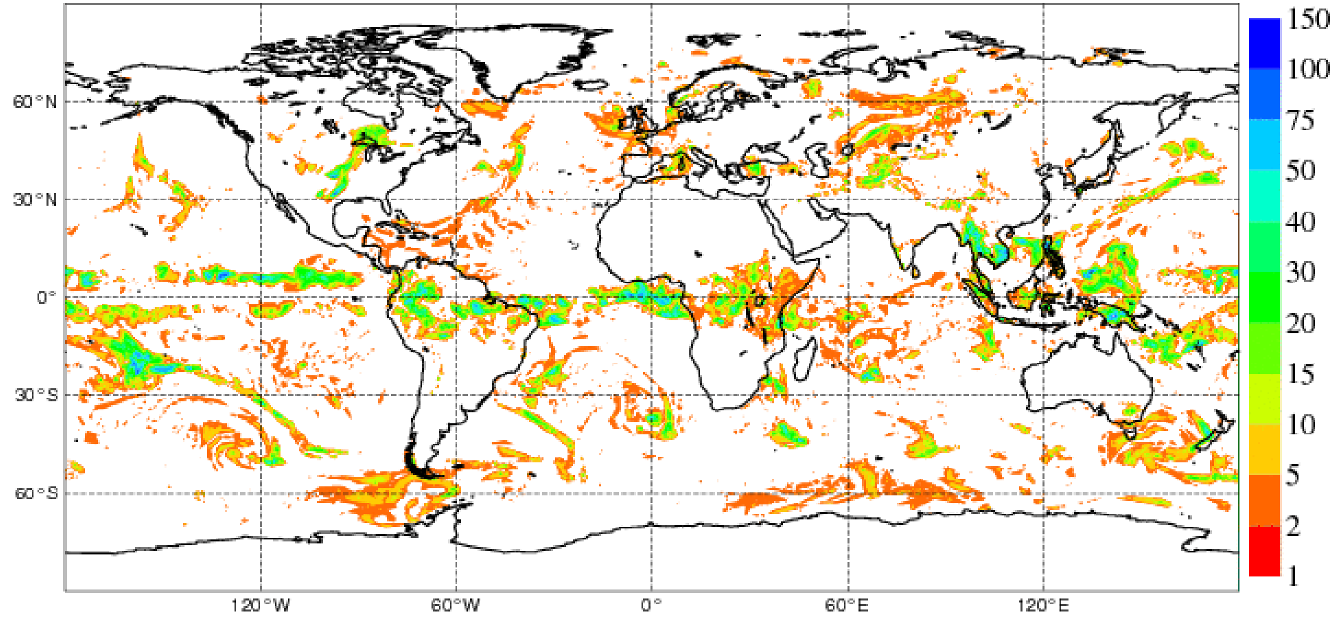


Precip

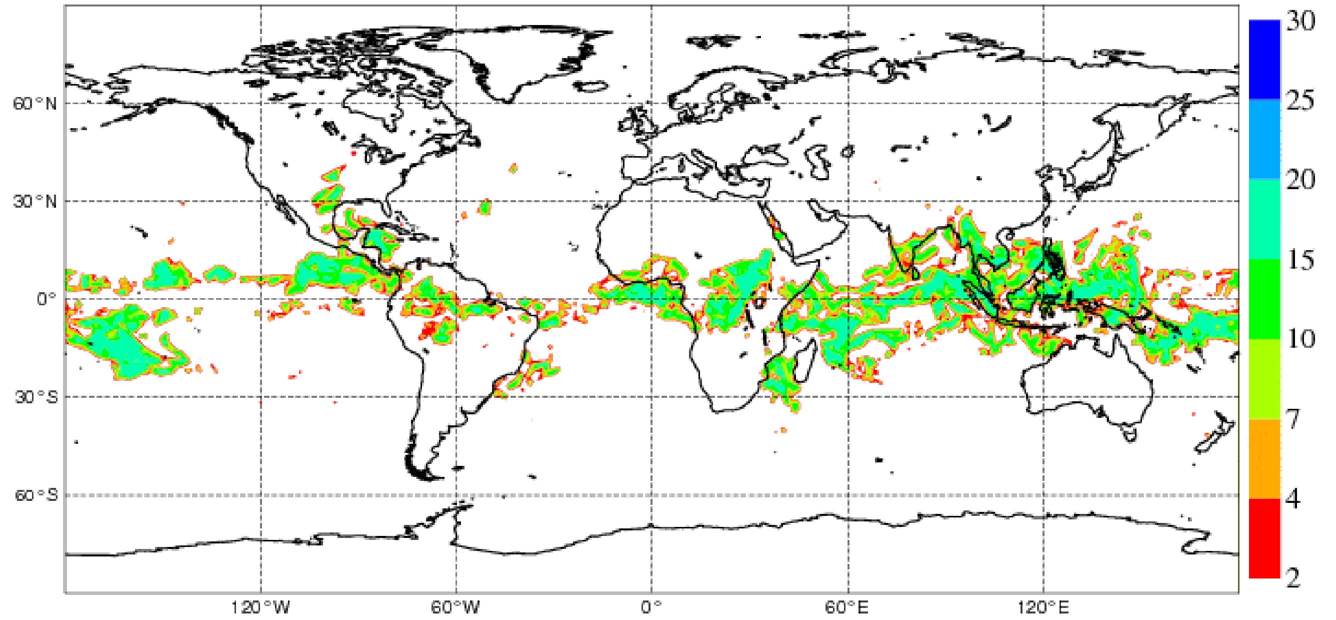


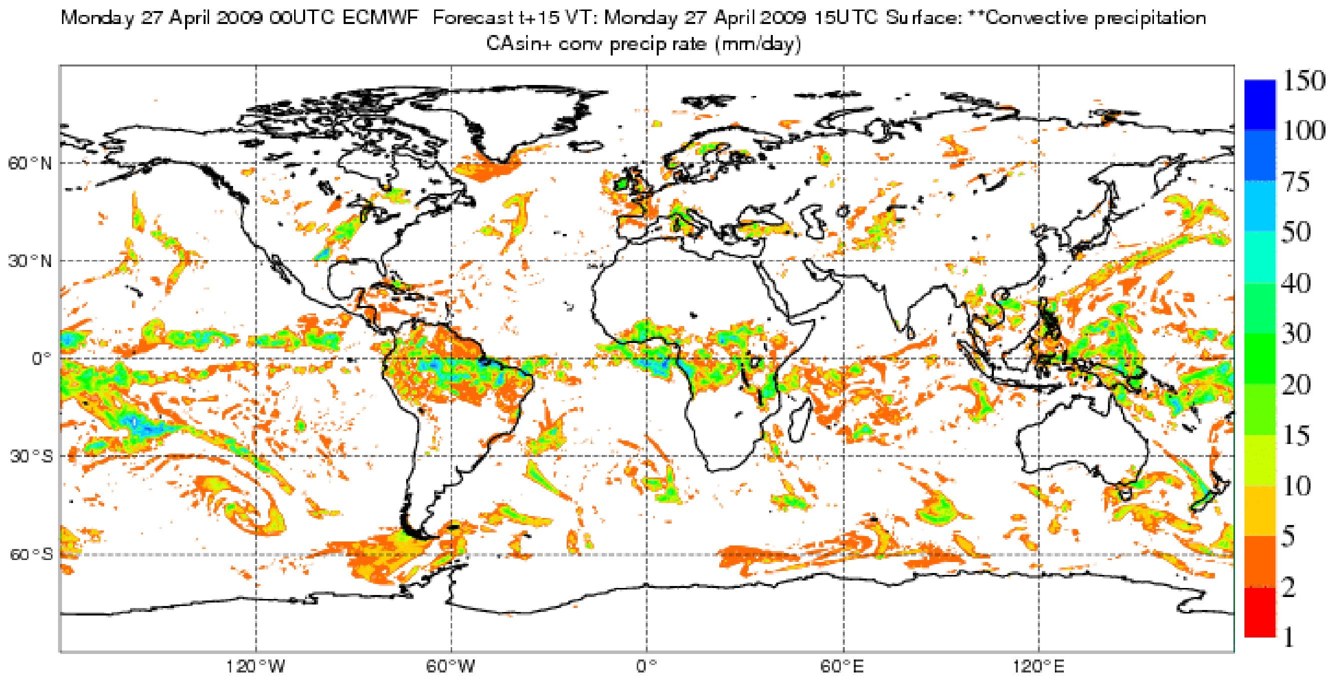
No of lives

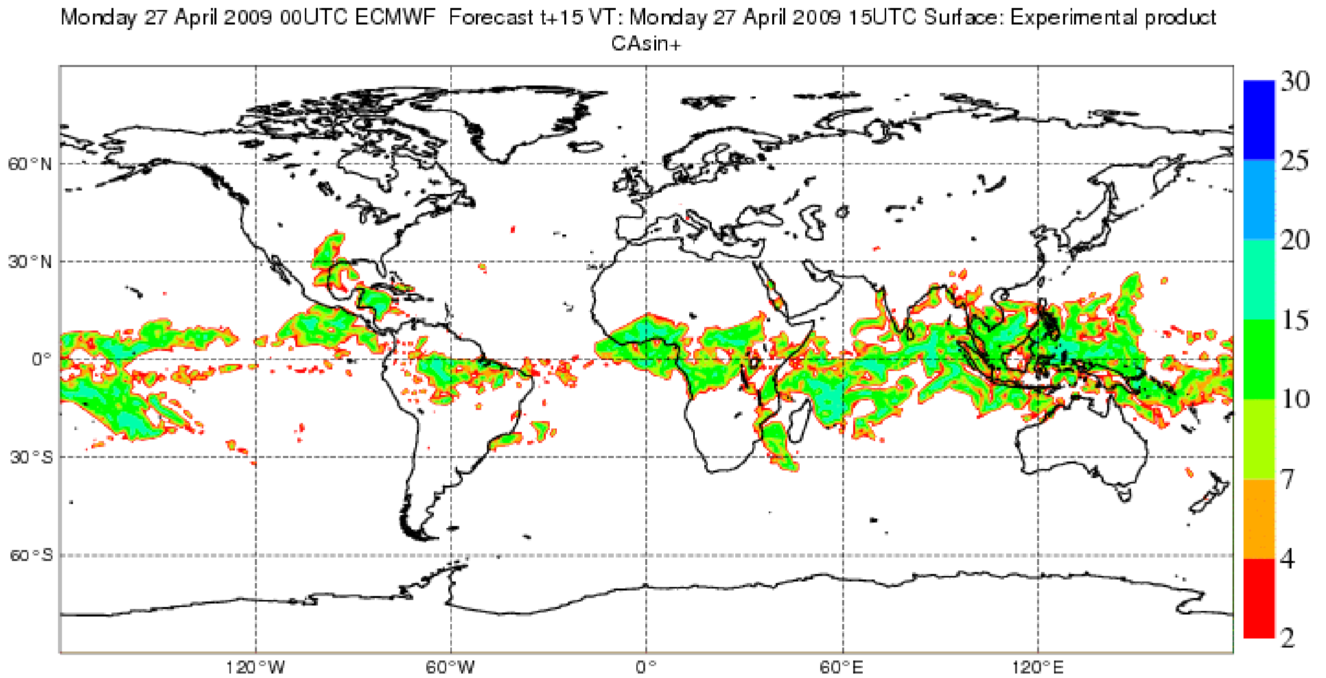
Monday 27 April 2009 00UTC ECMWF Forecast t+9 VT: Monday 27 April 2009 09UTC Surface: **Convective precipitation
CAsin+ conv precip rate (mm/day)



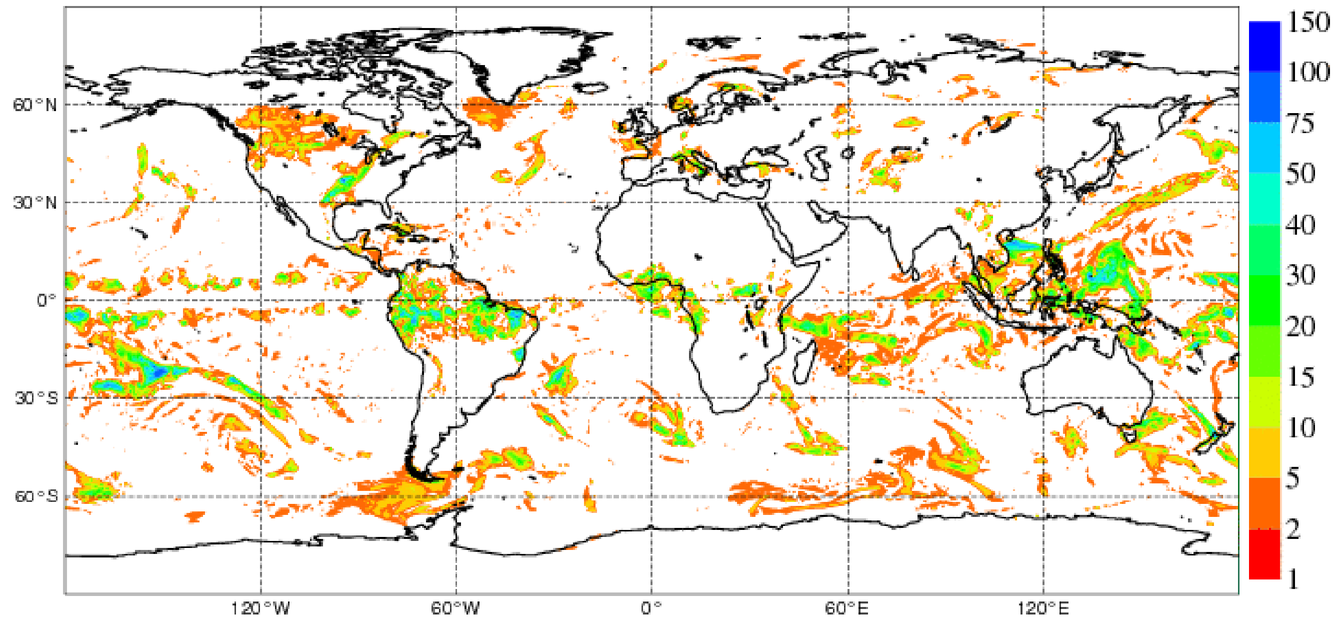
Monday 27 April 2009 00UTC ECMWF Forecast t+9 VT: Monday 27 April 2009 09UTC Surface: Experimental product
CAsin+



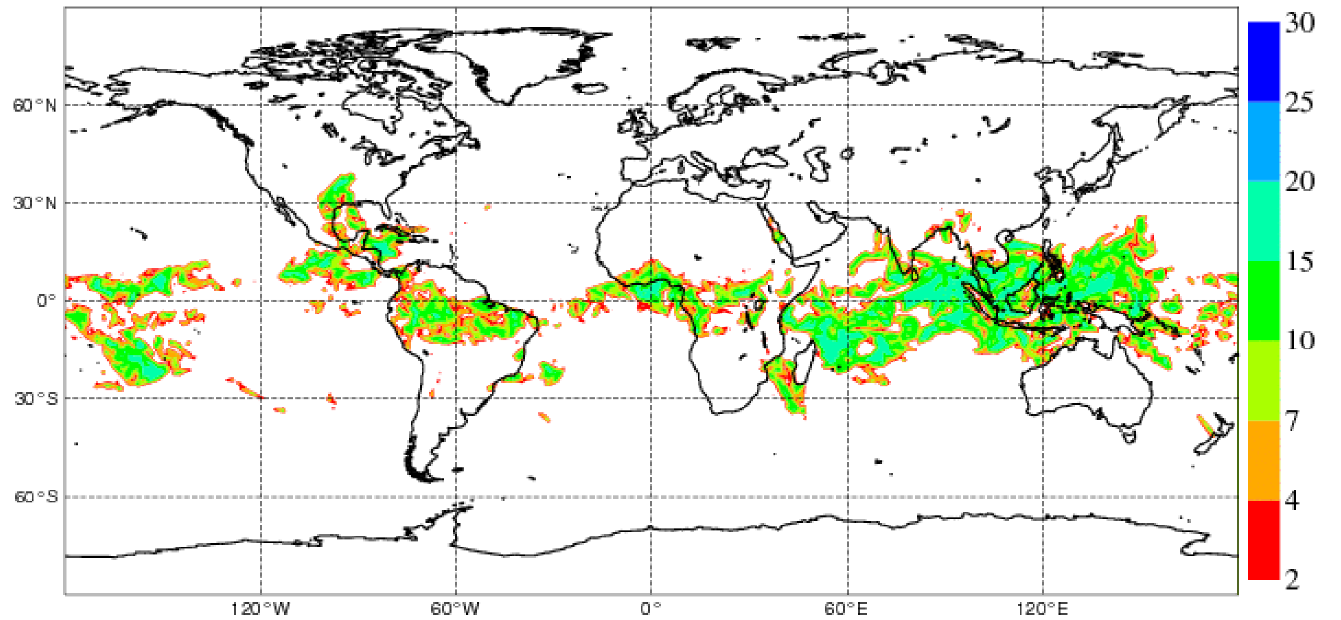

Monday 27 April 2009 00UTC ECMWF Forecast t+15 VT: Monday 27 April 2009 15UTC Surface: **Convective precipitation
CAsin+ conv precip rate (mm/day)
60°N
30°N
0°
30°S
60°S
120°W
60°W
0°
60°E
120°E
150
100
75
50
40
30
20
15
10
5
2
1

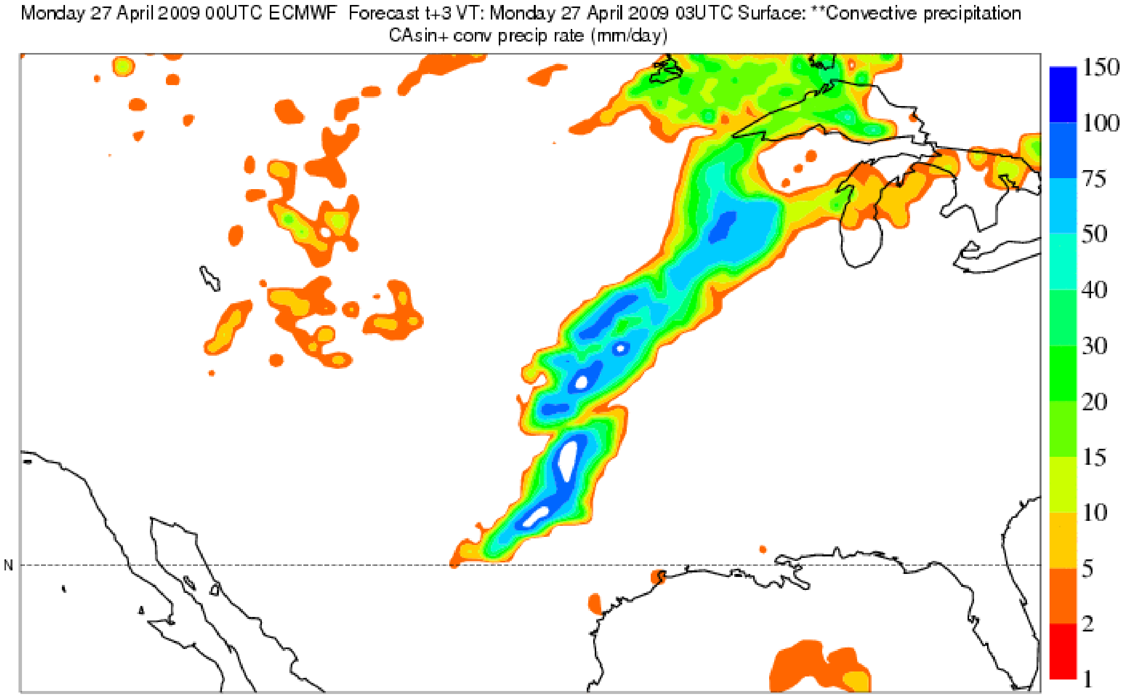

Monday 27 April 2009 00UTC ECMWF Forecast t+15 VT: Monday 27 April 2009 15UTC Surface: Experimental product
CAsin+
60°N
30°N
0°
30°S
60°S
120°W
60°W
0°
60°E
120°E
30
25
20
15
10
7
4
2

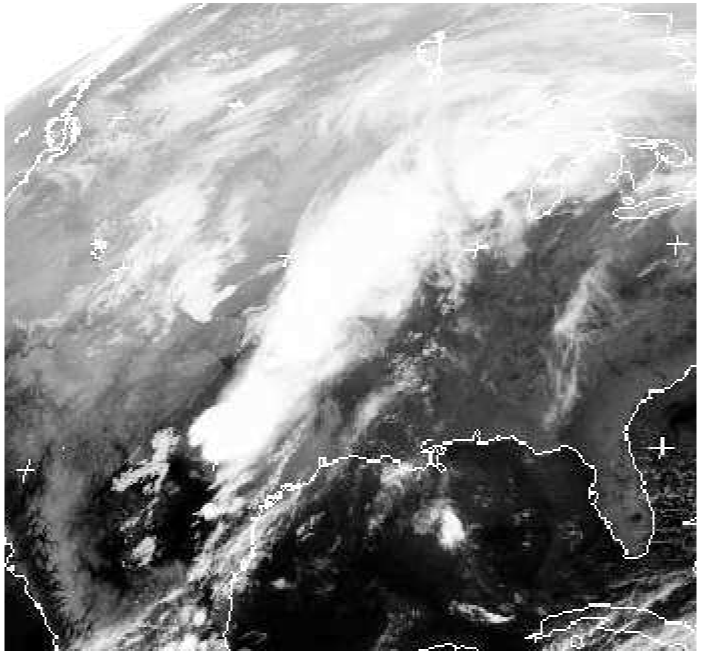
Monday 27 April 2009 00UTC ECMWF Forecast t+21 VT: Monday 27 April 2009 21UTC Surface: **Convective precipitation
CAsin+ conv precip rate (mm/day)

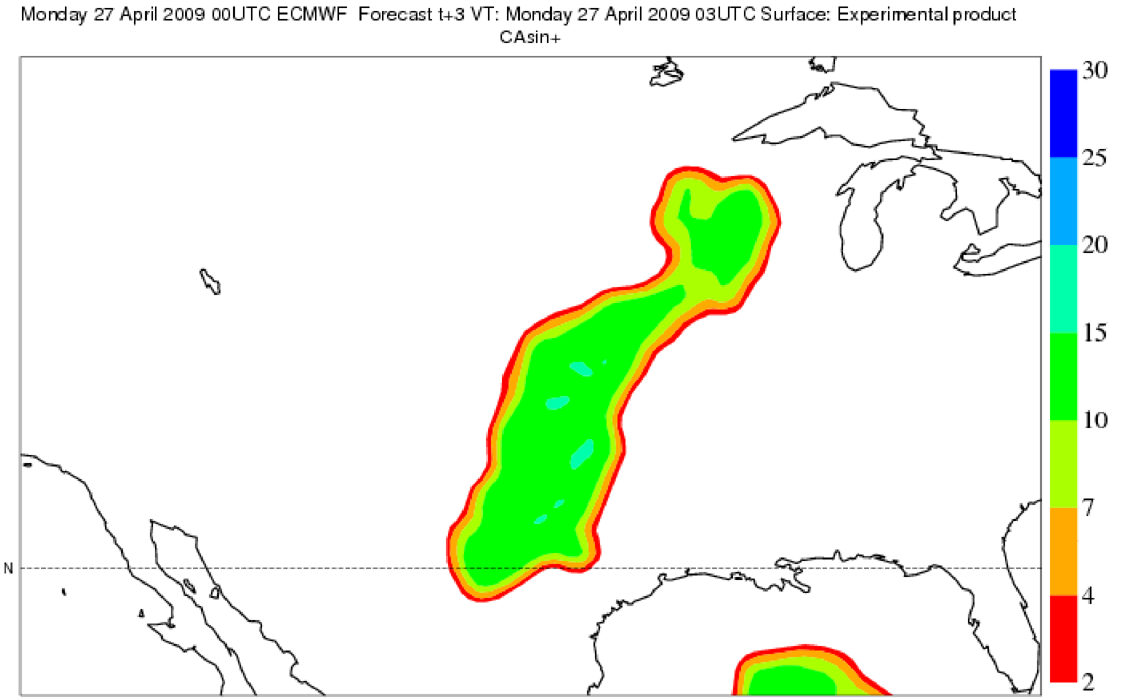


Monday 27 April 2009 00UTC ECMWF Forecast t+21 VT: Monday 27 April 2009 21UTC Surface: Experimental product
CAsin+

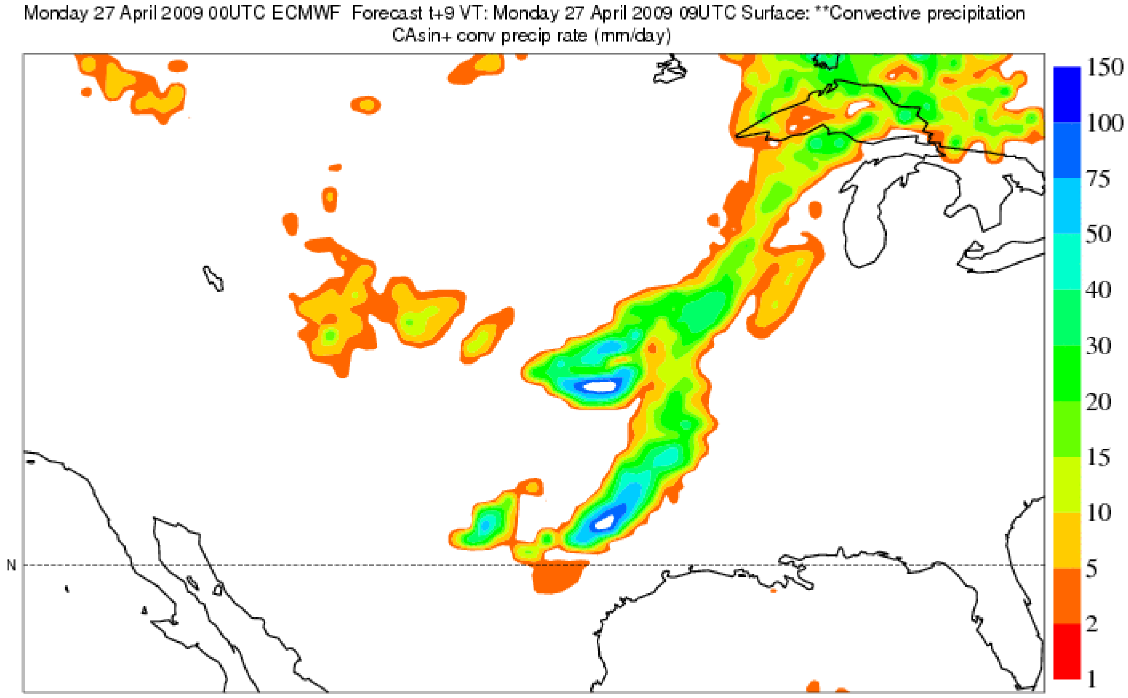


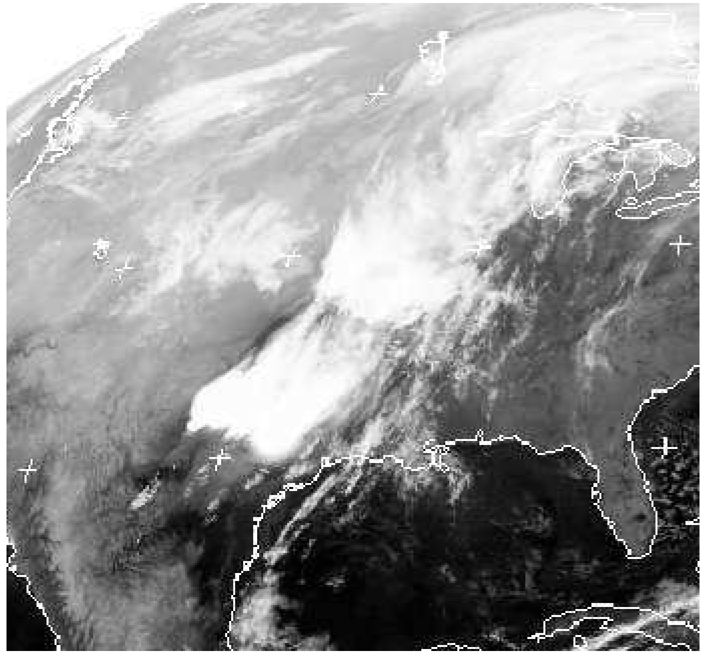


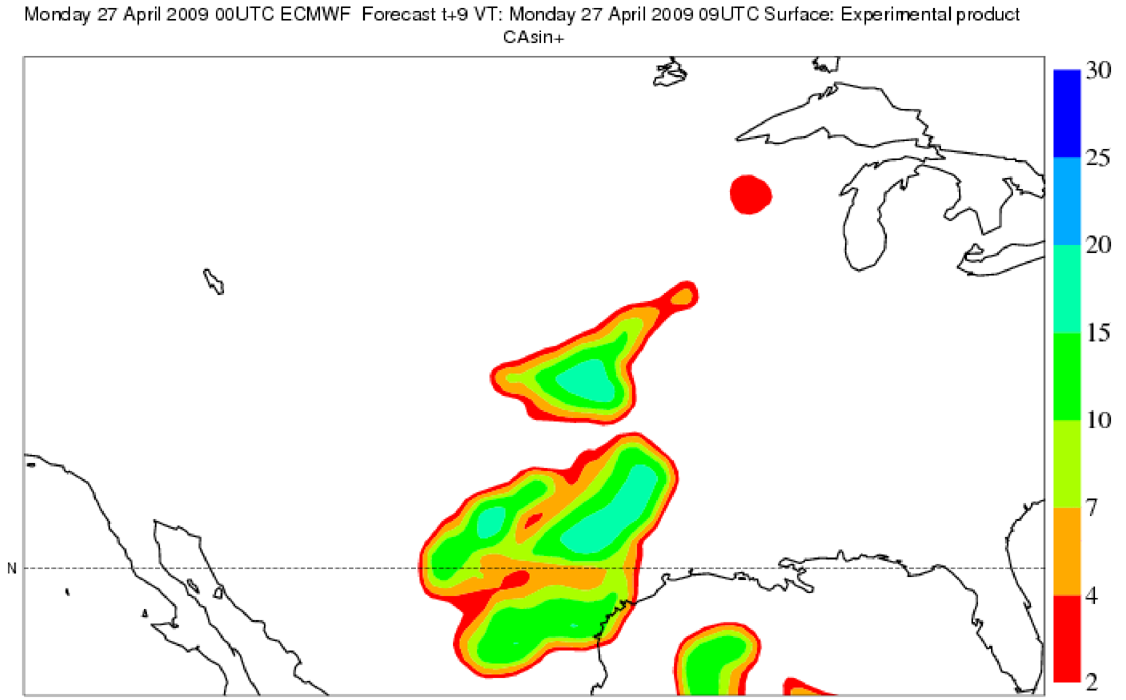




Zoom on North America



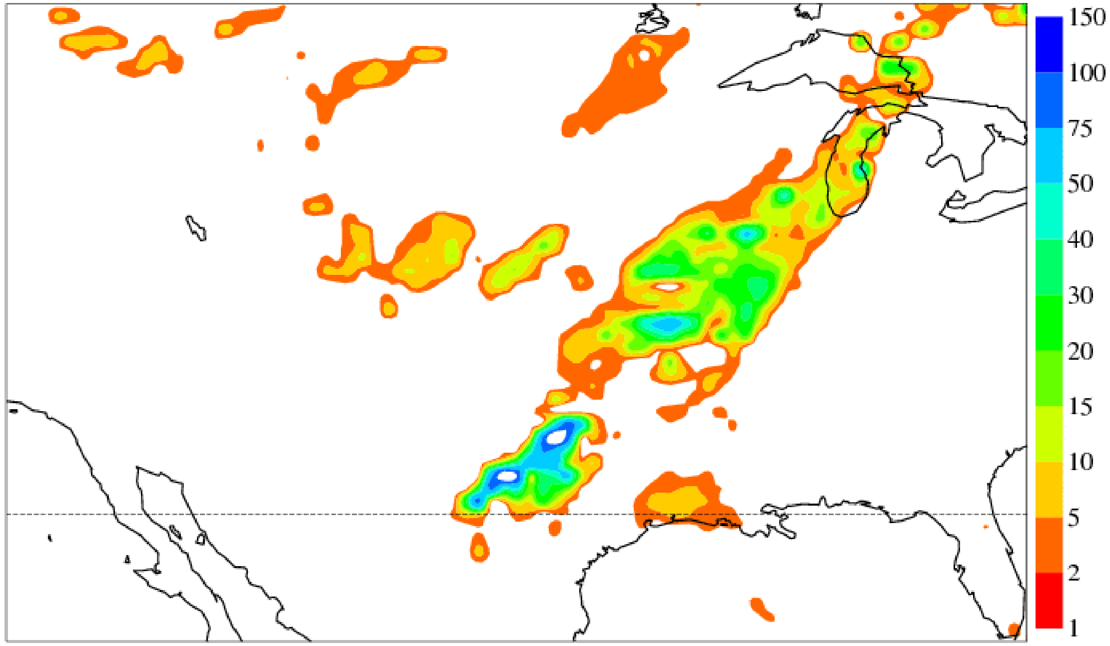


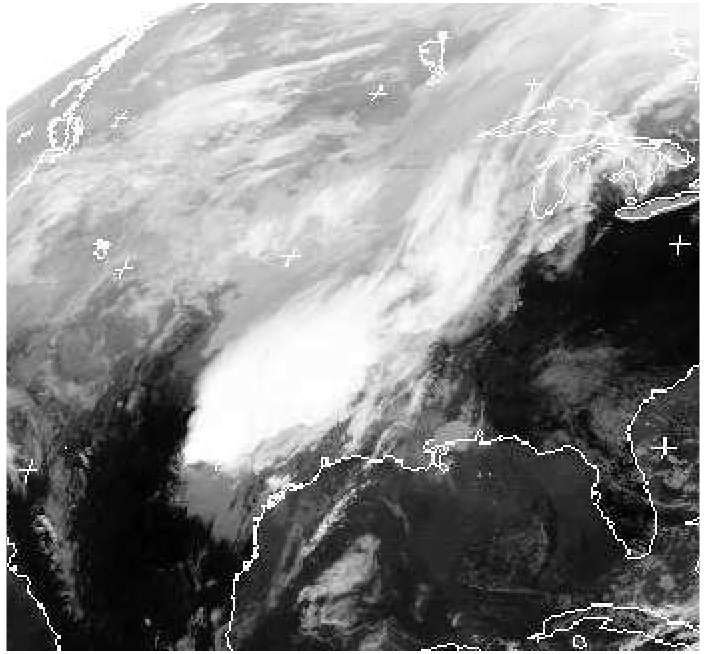


CA is ahead of convection

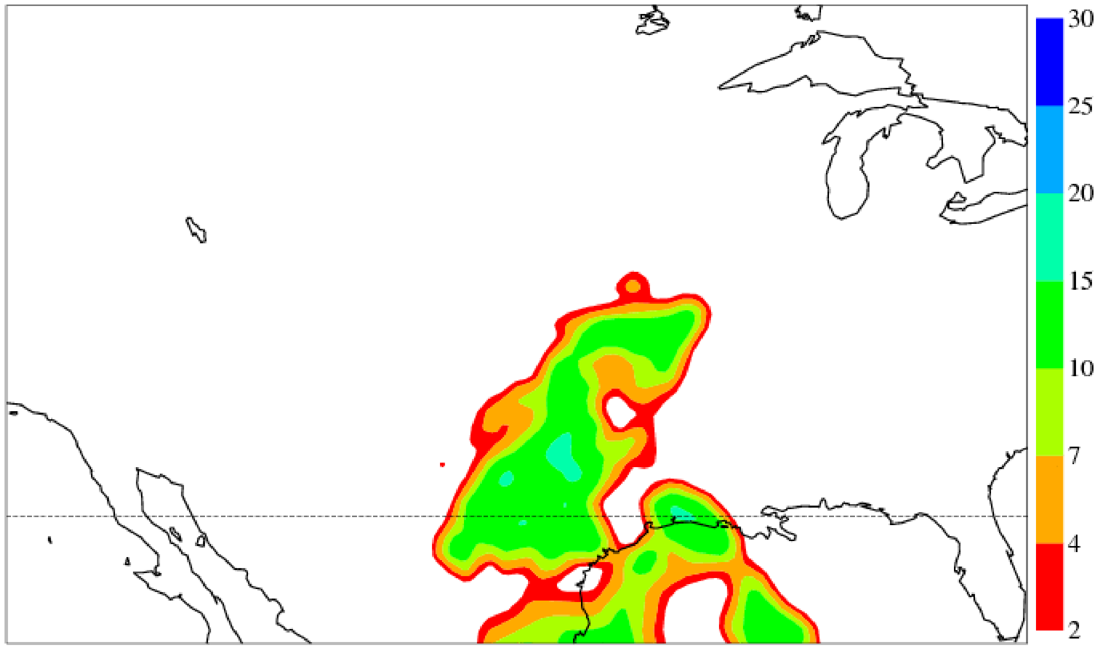
Reminer: this is where we perturb input profile for convection

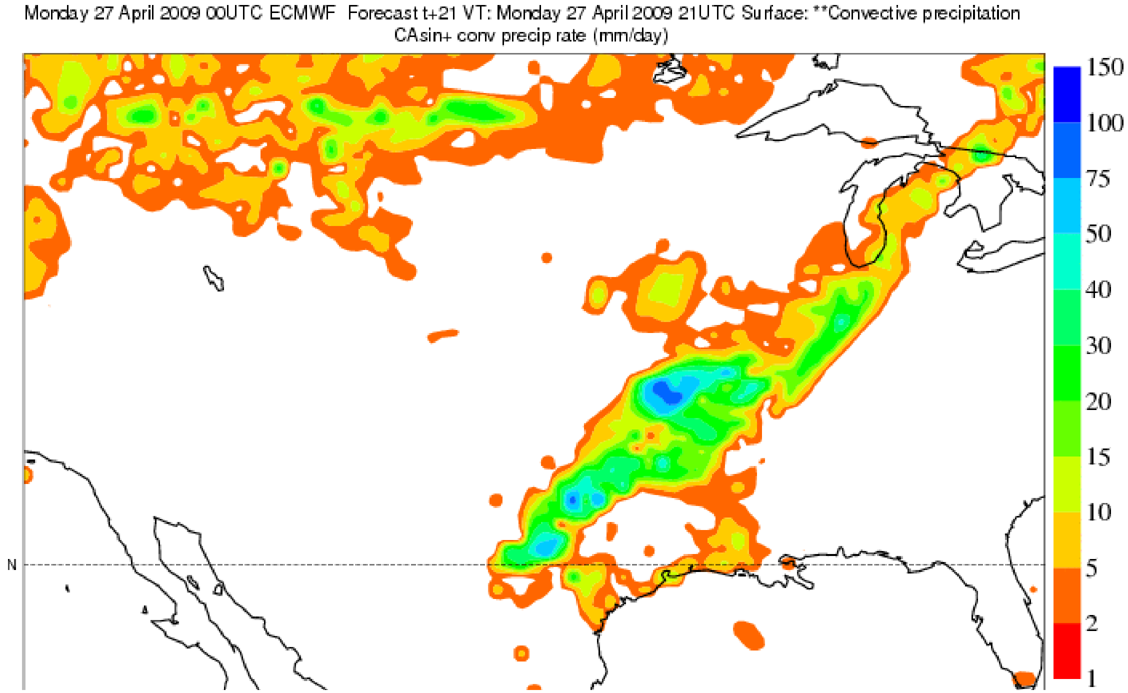
Monday 27 April 2009 00UTC ECMWF Forecast t+15 VT: Monday 27 April 2009 15UTC Surface: **Convective precipitation
CAsin+ conv precip rate (mm/day)

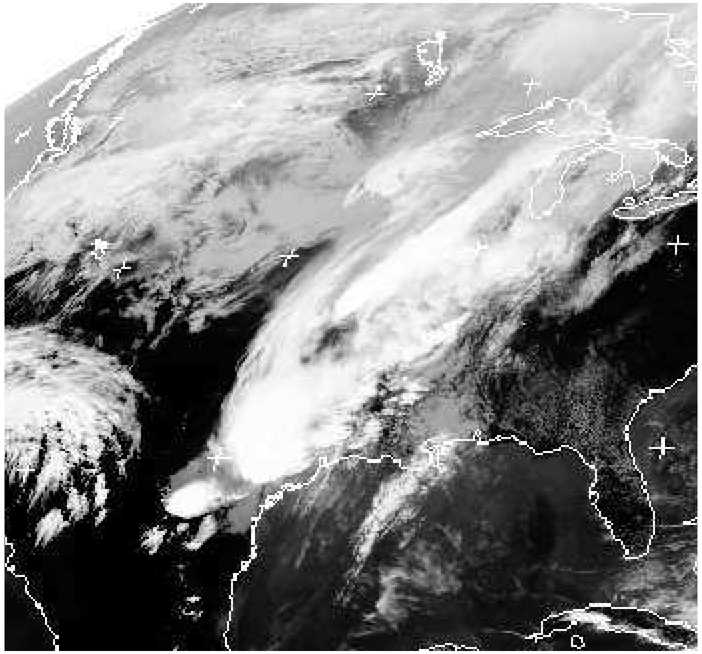


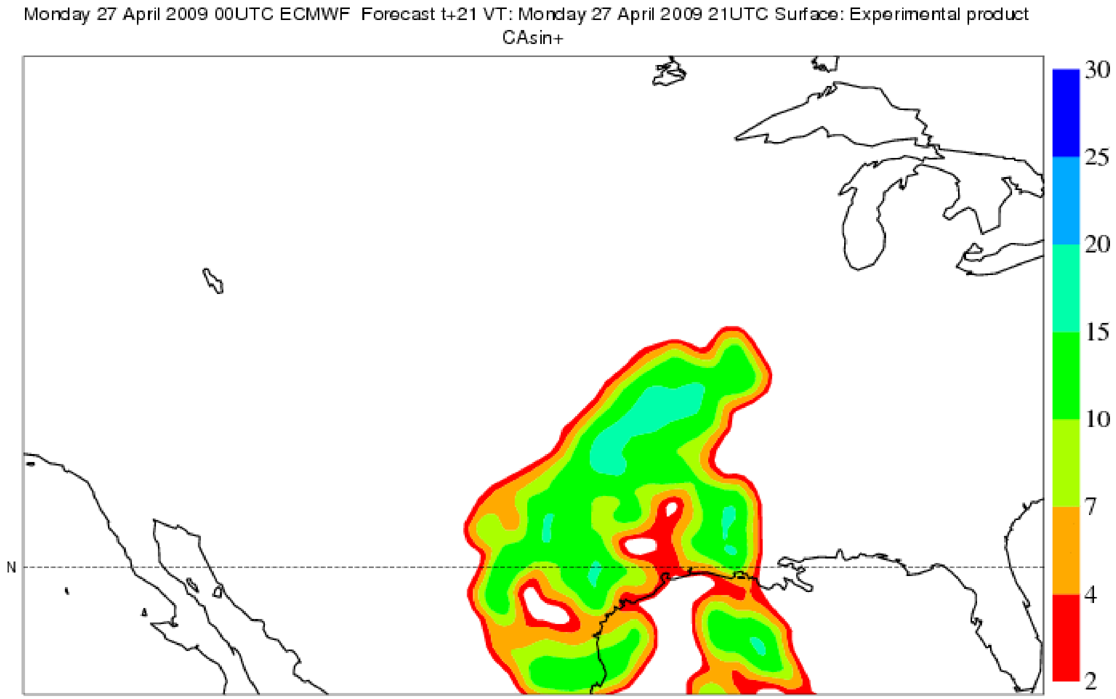


Monday 27 April 2009 00UTC ECMWF Forecast t+15 VT: Monday 27 April 2009 15UTC Surface: Experimental product
CAsin+









Conclusions: seems to be reasonable physically and technically but only small impact do far

Other possibilities to improve representation of convection

Some prognostic approach

………already in place in ALARO

Pros:

- Provides memory for convection
- Includes horizontal advection (e.g. better inland penetration of showers)

Cons:

- Need to specify for each equation additional constant (dissipation time)
- Does one wish to have also the vertical advective part? Impact on consistency with convection budgets
- Which variables? Keep minimum

Preliminar experiments with 1 prognostic equation e.g for Convective Precipitation flux

$$\frac{\partial \psi}{\partial t} = \frac{\psi_{conv} - \psi}{\tau_{prod}} - \frac{\psi}{\tau_{diss}}$$

where ψ_conv is the value diagnosed from the convection scheme.

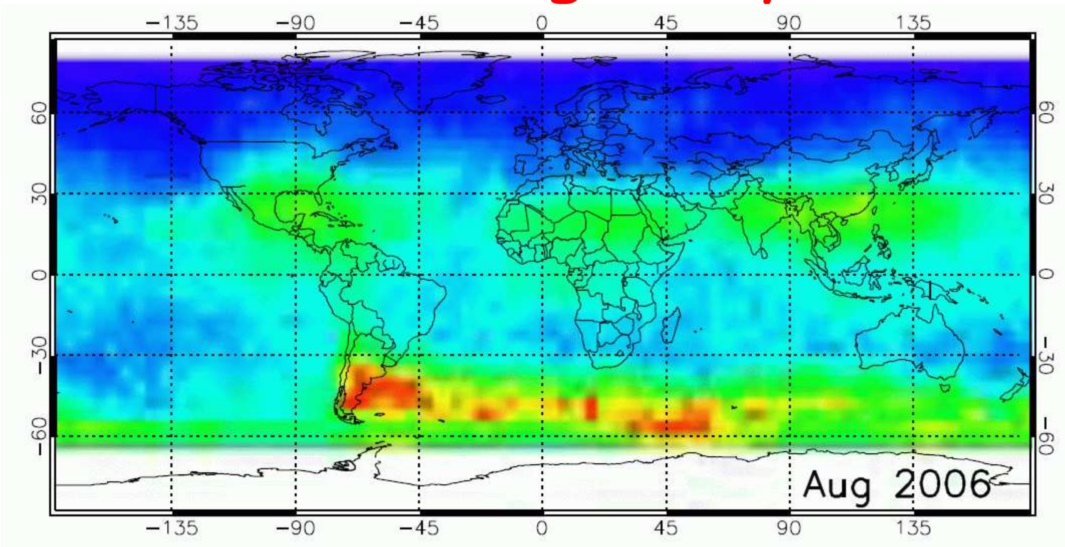
Test can this reasonably reproduce diagnostic value? Final approach could be combimation or difference of both to account for advective affect

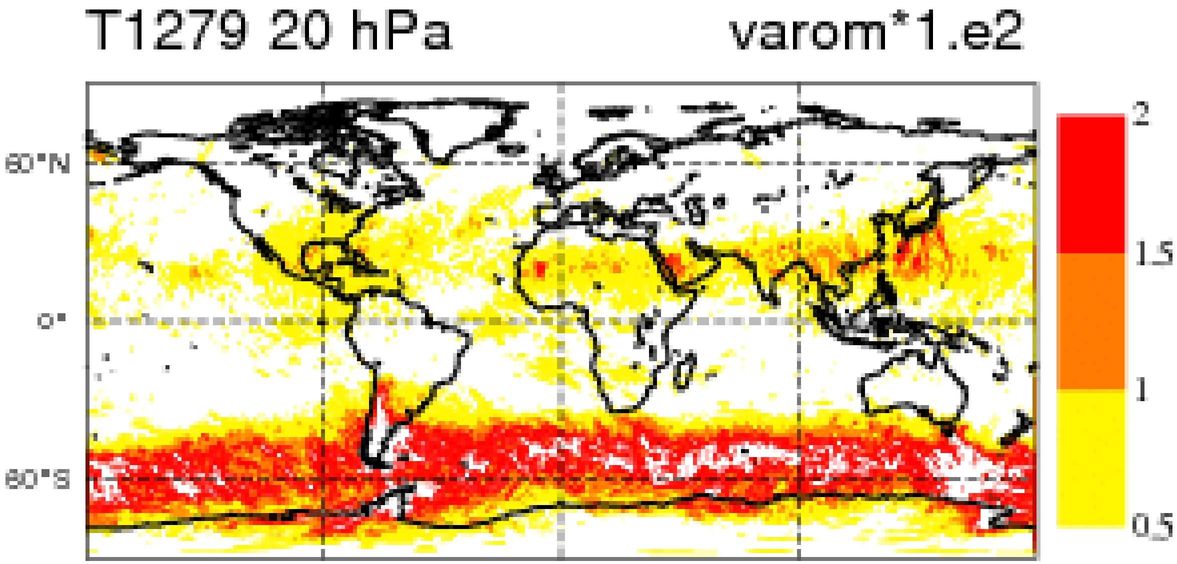
Gravity waves, in particular non-orographic gravity waves (convection, fronts etc.)

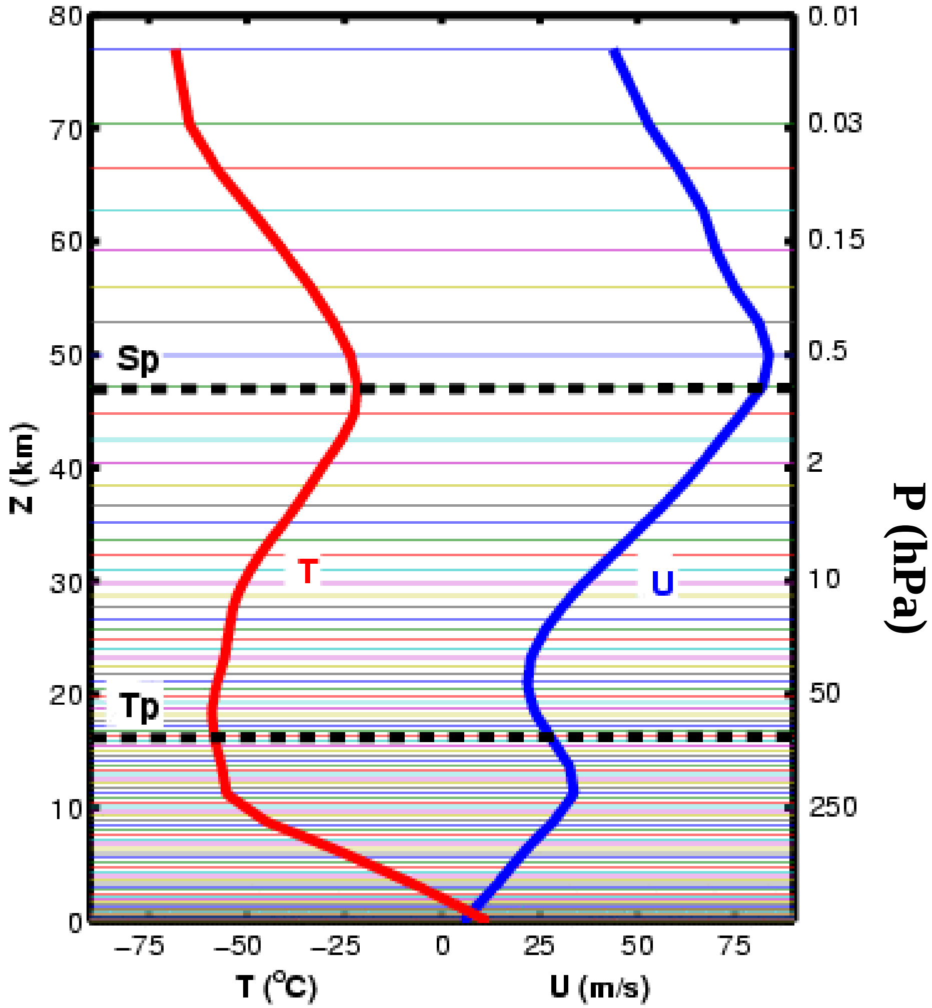
Resolution dependence and circulation of the middle atmosphere

Influence on tropospheric predictions ?

Observations (Yan et al. 2009 from limb sounder) versus model resolved gravity wave diagnostic







Typical Temperature and Zonal Wind profiles for July at 40S, together with the distribution of the 91-levels in the IFS. **Tp** denotes the **Tropopause**, **Sp** the **Stratopause**, the model top also corresponds to the **Mesopause**

Structure of the Atmosphere: Troposphere & Stratosphere

- Temperature decrease in the Troposphere is due to adiabatic decompression
- Midlatitude upper-tropospheric Jet form due to strong temperature gradient between Pole and Equator.
- The temperature in the Stratosphere increases due to the absorption on solar radiation by ozone

Distinguishing between resolved and unresolved (parametrized) waves.

the Eliassen Palm flux vectors

$$EPVector = \left\langle -R\cos\phi\,\overline{u^{*}v^{*}},\ f\,R\cos\phi\,\overline{v^{*}\theta^{*}}\left(\partial\theta/\partial p\right)^{-1}\right\rangle$$

$$f = Coriolis; \quad \phi = latitude; \quad \theta = pot.temperature$$

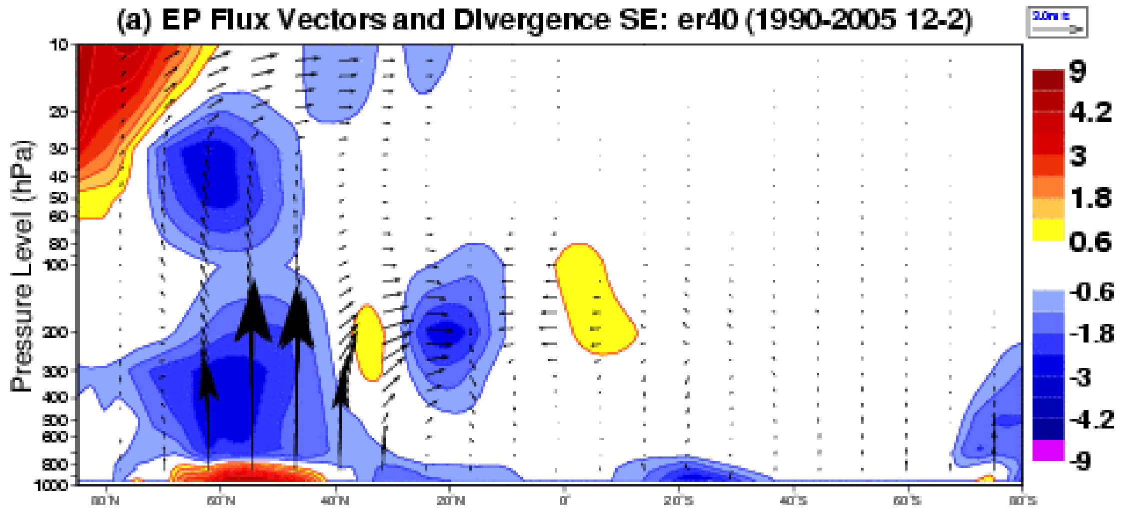
$$*\,denote\ anomalies\ \ from\ zonal\ mean$$

$$\left(Peixoto\,\&\,Oort\ \ 1992,\ p.388\right)$$

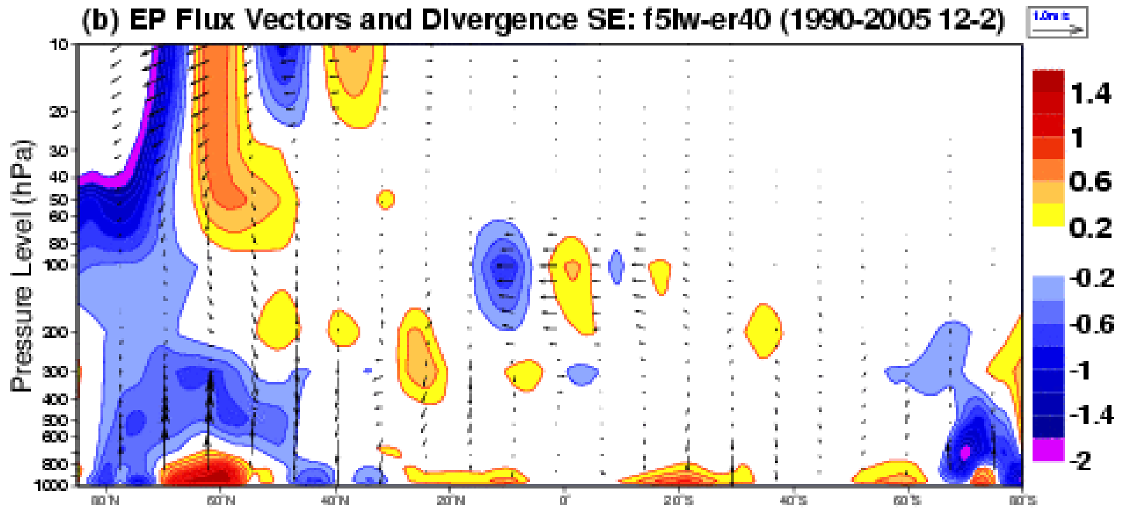
- EP Flux vectors give the net wave propagation for stationary Rossby waves (group speed theorem)
- Stationary Rossby waves are particularly prominent in the NH during winter. They propagate from the troposphere upward into the stratosphere

Resolved stationary Rossby waves: EP-Fluxes in Winter

ERA40



Cy35r3-ERA40

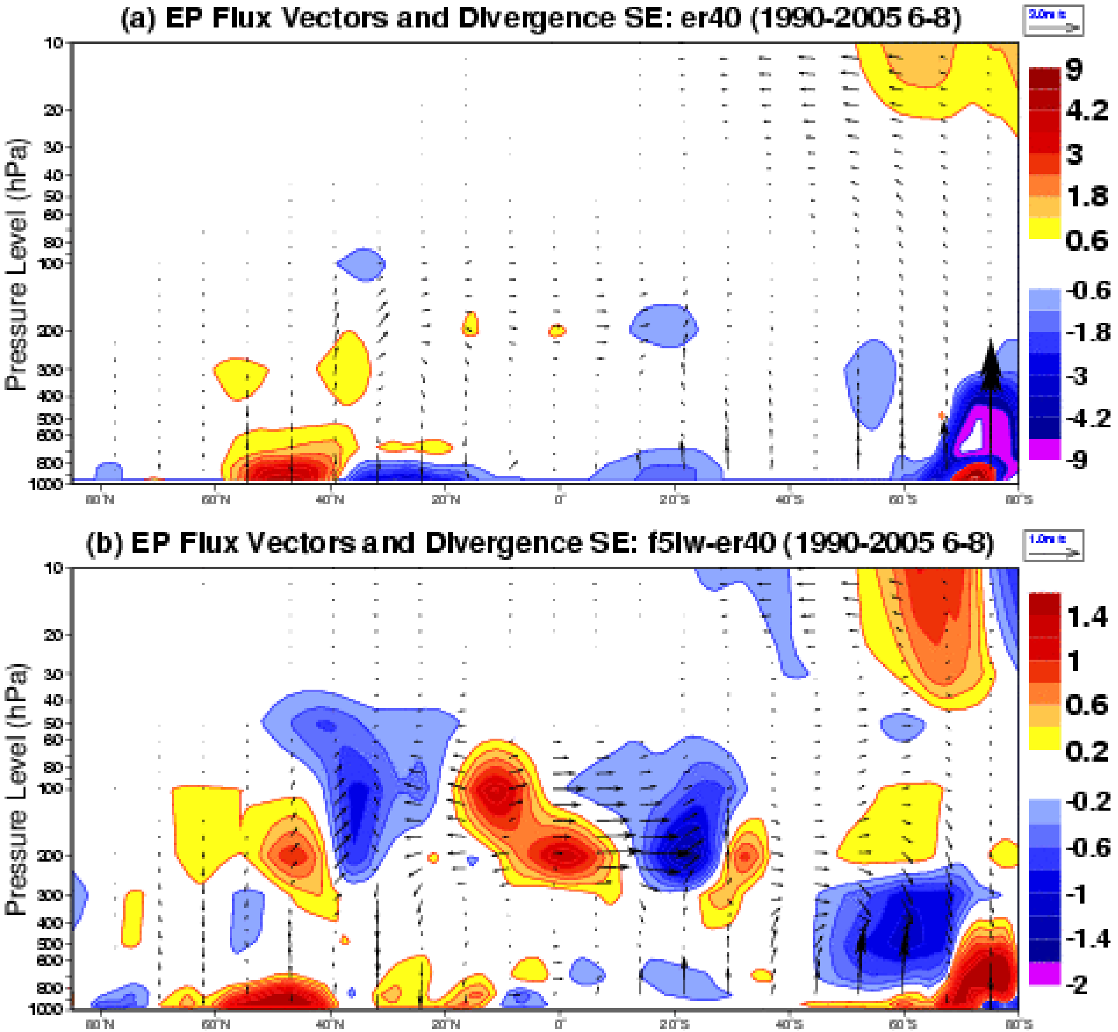


Stationary Rossby waves are particularly prominent in the NH during winter. They propagate from the troposphere upward into the stratosphere

Resolved stationary Rossby waves: EP-Fluxes in Summer

ERA40

Cy35r3-ERA40



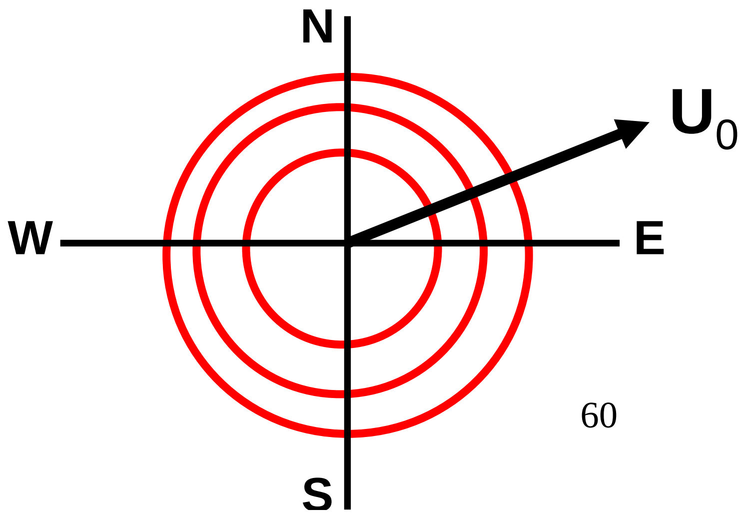
What is a “ non-orographic” gravity wave?

Orographic gravity waves are supposed to be stationary (ω=0)

Non-orograpgic gravity waves are non-stationary, and therefore have non-zero phase speed. The parametrization problem is therefore 5-dimensional!

$$\Psi(j, z, k, \omega, \phi)$$

Depending on gridpoint *j*, height *z*, wavenumber *k*, frequency ω, and direction Φ



Parameter specification

1) t=3 (fixed)
2) p=1 (or 3/2 ; observed/theoretical $1 \leq p \leq 5/3$)
3) s=1 (or 0,1; s=1 most common, ie positive slope required)
4) m* (= $2\pi/2km$, see Ern et al (2006))
5) C* (=1; raising this raises the height momentum is deposited)
6) φ =4 (number of azimuths, although can have 8, 16, …)

7) z_0 (launch level; Ern et al. (2006) suggests either 450 hPa or 600 hPa)
8) $\rho_0 F_0$ input momentum flux into each azimuth is set to 3.75 $x10^{-3}$ (Pa)

Ern, Preusse, and Warner, 'Some experimental constraints for spectral parameters used in the Warner and McIntyre gravity wave parameterization scheme', Atmos. Chem. Phys., 6, 4361-4381, 2006

Evaluation: Run ensemble of T159 (125 km) 1-year climate runs and compare mean circulation and temperature structure against SPARC dataset

- Cy35r2 (operational since 10 March 2009). Uses so called Rayleigh friction, a friction proportional to the zonal mean wind speed, to avoid unrealistically high wind speeds (polar night jet) in middle atmosphere. The trace gas climatology (CO2, CH4 etc) consist of globally constant values, apart from ozone

- Cy35r3 (becoming operational in summer 2009) includes a new trace gas climatology (GEMS reanalysis + D. Cariolle fields), zonal mean fields for every month, and the described non-orographic gravity wave parametrisation

January

NH

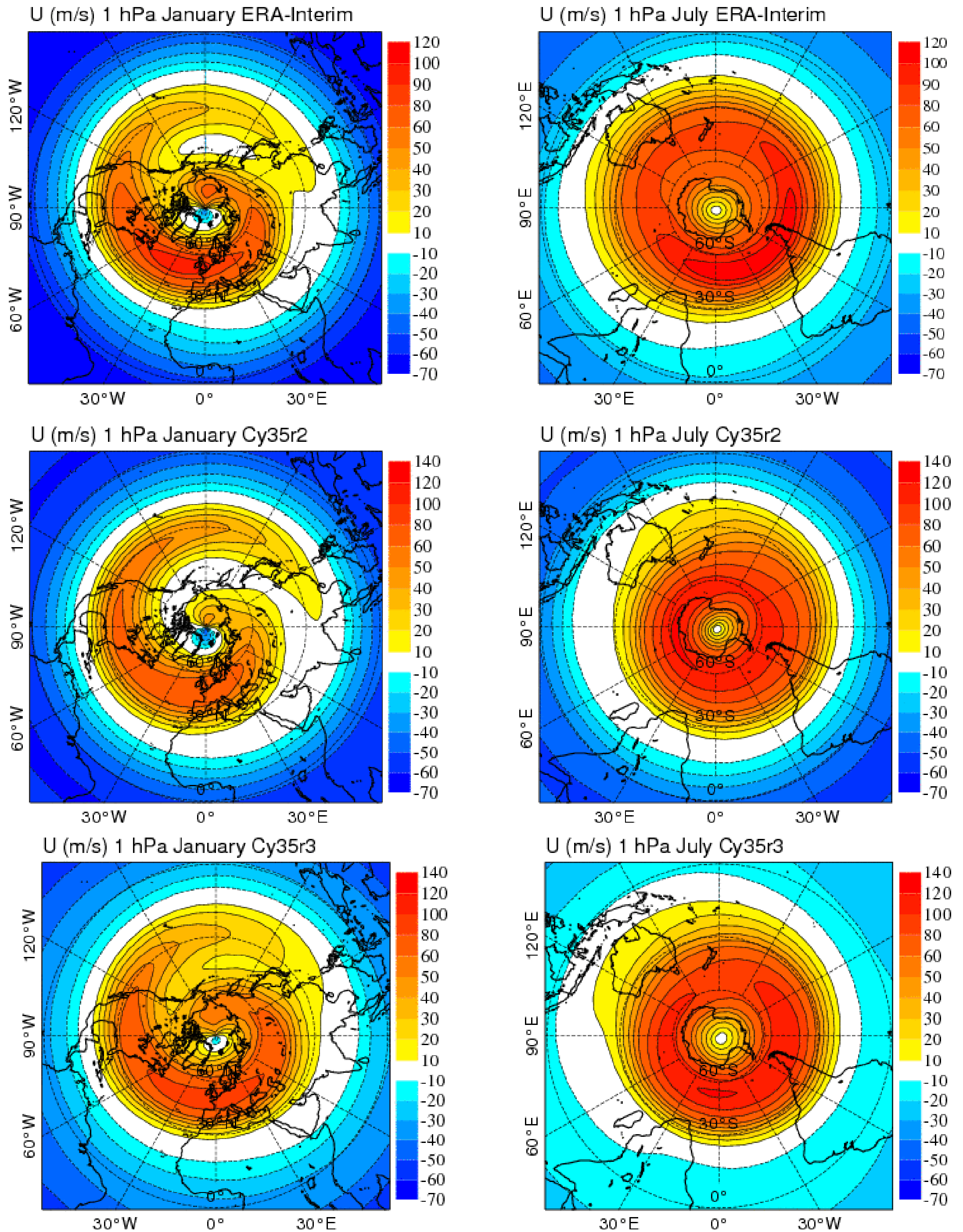
ERA

Cy35r2

March 2009

Cy35r3

Summer 2009 with GWD + GHG



July

SH

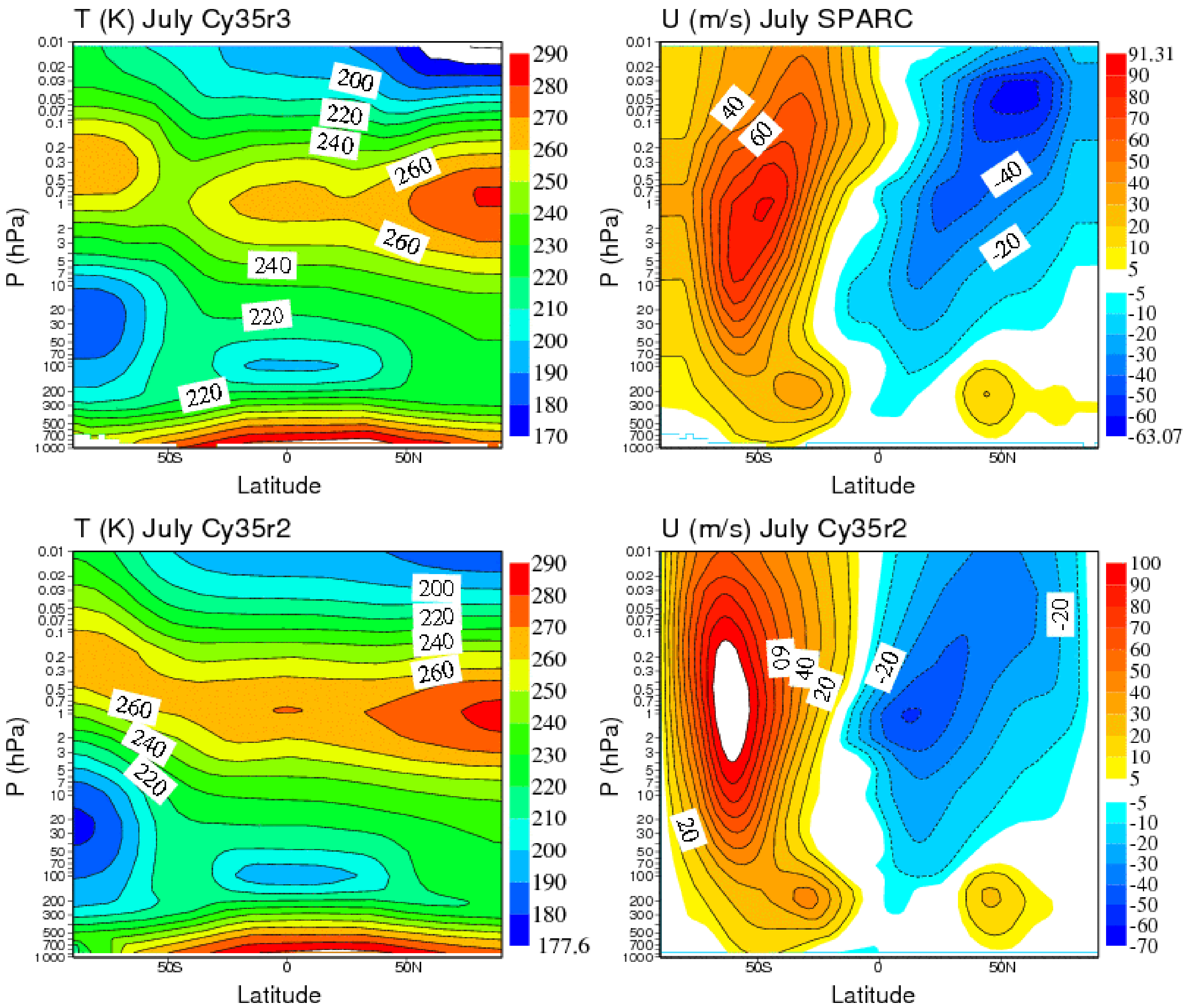
Polar winter vortex

SH wintertime vortex is quasi-symmetric, but not NH polar vortex, due to braking quasi-stationary Rossby waves emanating in the troposphere

July climatology

SPARC

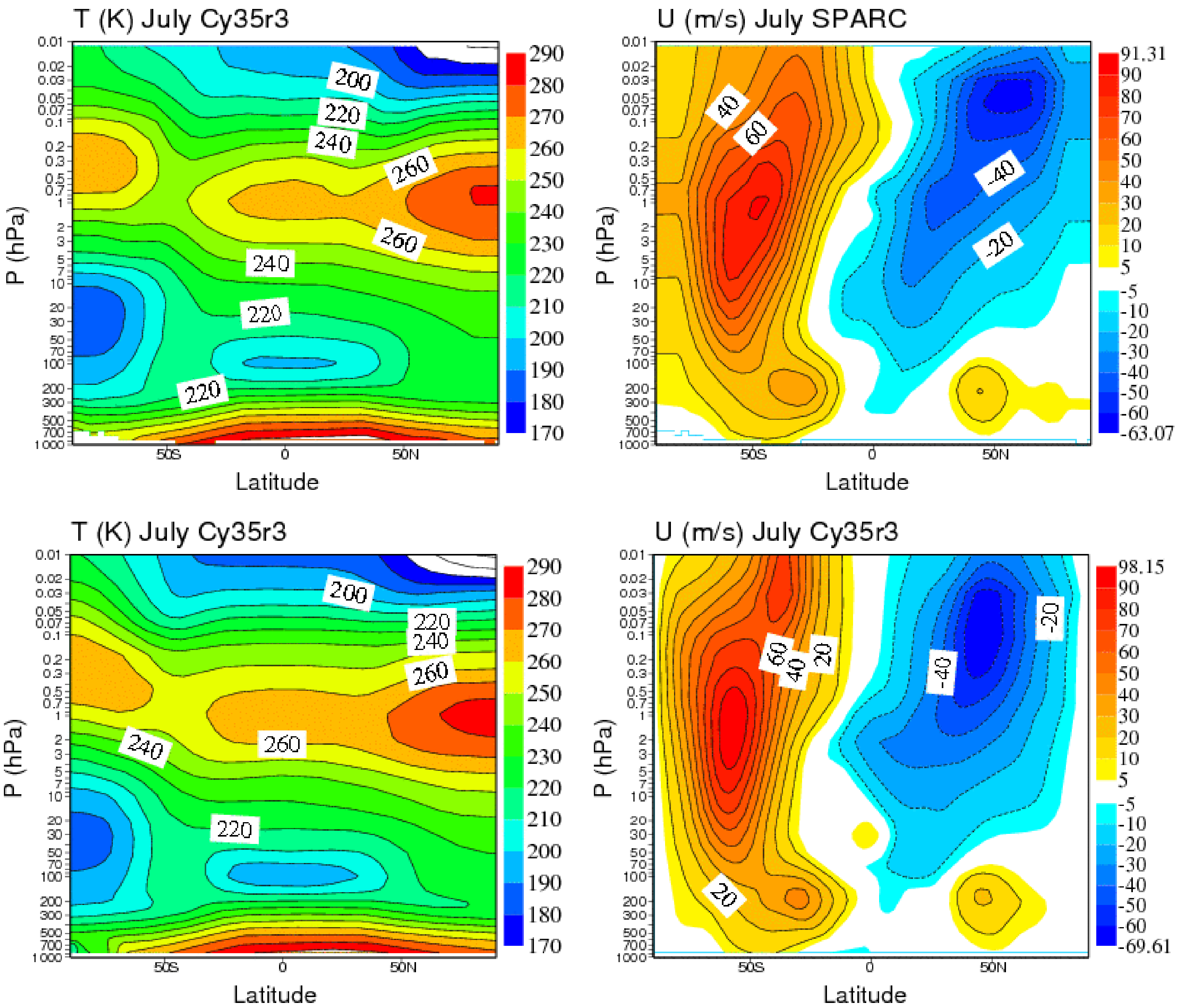
35r2



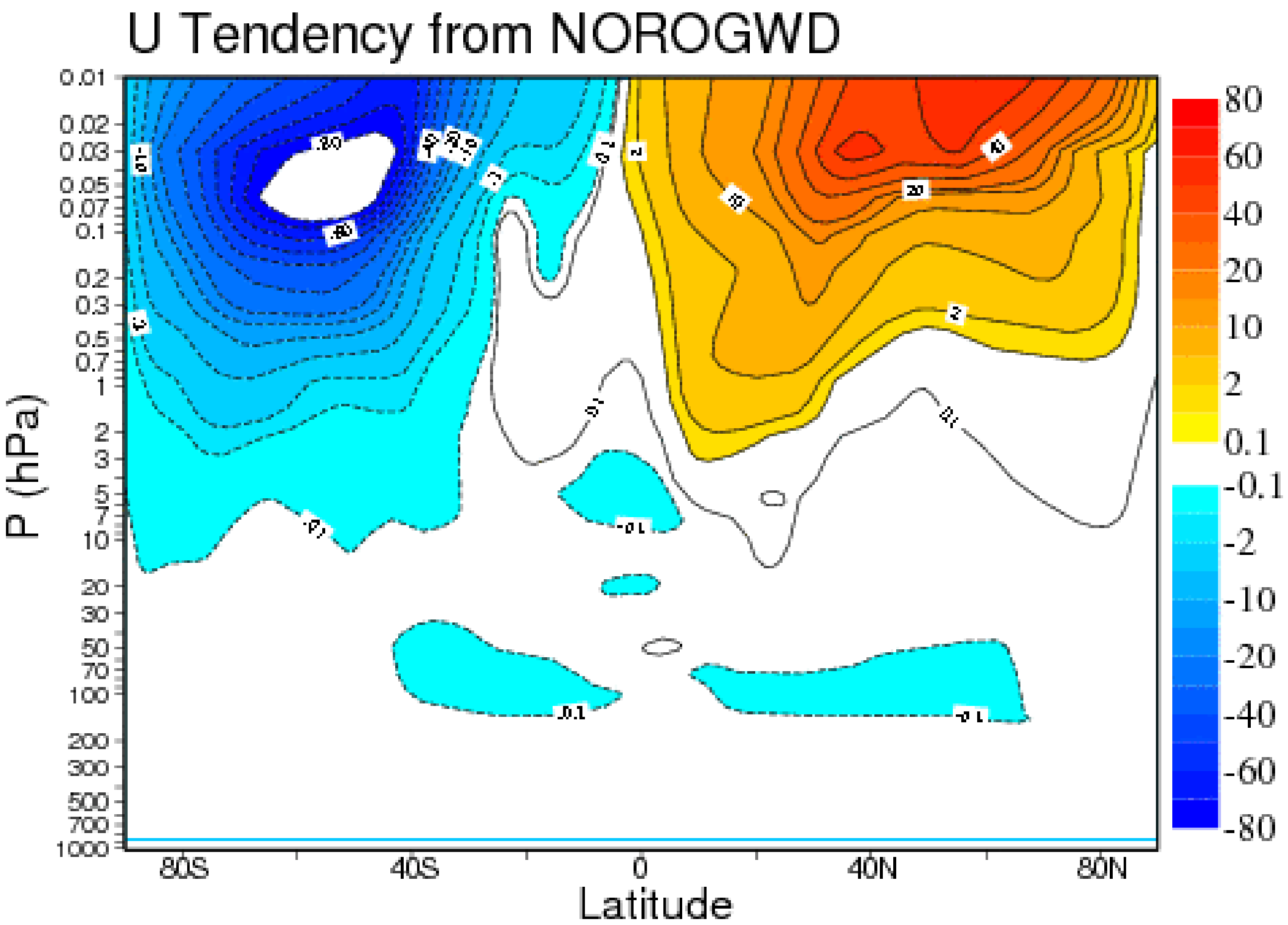
July climatology

SPARC

35r3

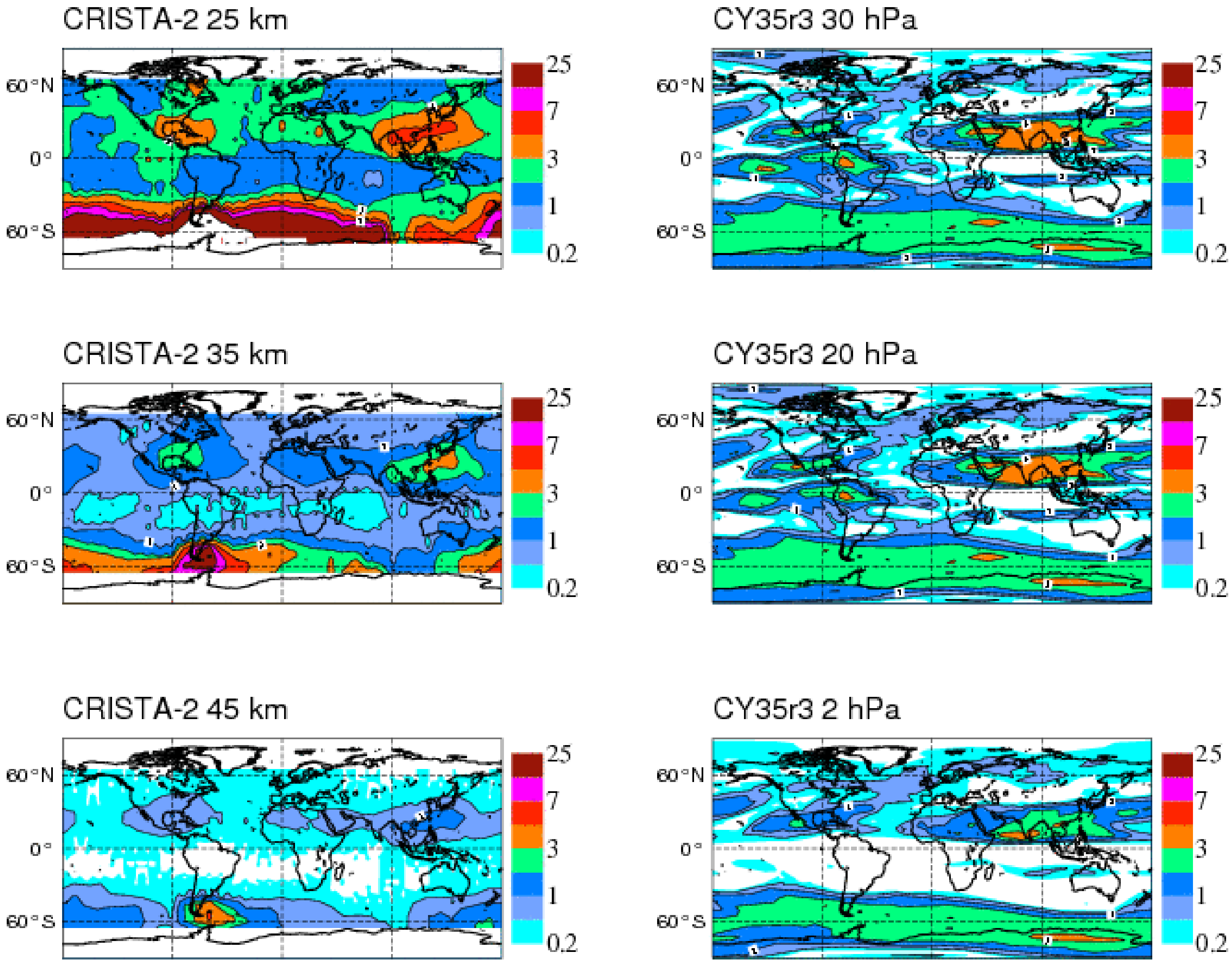


U Tendencies (m/s/day) July from non-oro GWD



Conclusions from comparison against SPARC & ERA-Interim reanalysis

- Polar vortex during SH winter quasi symmetric, but asymmetric NH winter polar vortex, due to vertically propagating quasi-stationary Rossby waves (linked to mountain ranges)
- In Cy35r2 (no GWD parameterization) SH polar vortex too strong, westerly polar night Jet is wrongly tilted with height, large T errors in mesosphere. Jet maximum in summer hemisphere easterly jet at wrong height (at stratopause instead of mesopause)
- In Cy35r3 improved tilt of the polar Jet with height towards the Tropics, allover improved winter hemisphere westerly and summer hemisphere easterly jets. The smaller warm bias around the stratopause is due to the improved greenhouse gas climatology
- Results qualitatively similar for January, invert NH and SH



Comparison of observed and simulated momentum flux for 8-14 August 1997 horizontal distributions of absolute values of momentum flux (mPa) Observed values are for CRISTA-2 (Ern et al. 2006). Observations measure temperature fluctuations with infrared spectrometer, momentum fluxes are derived via conversion formula.

The QBO

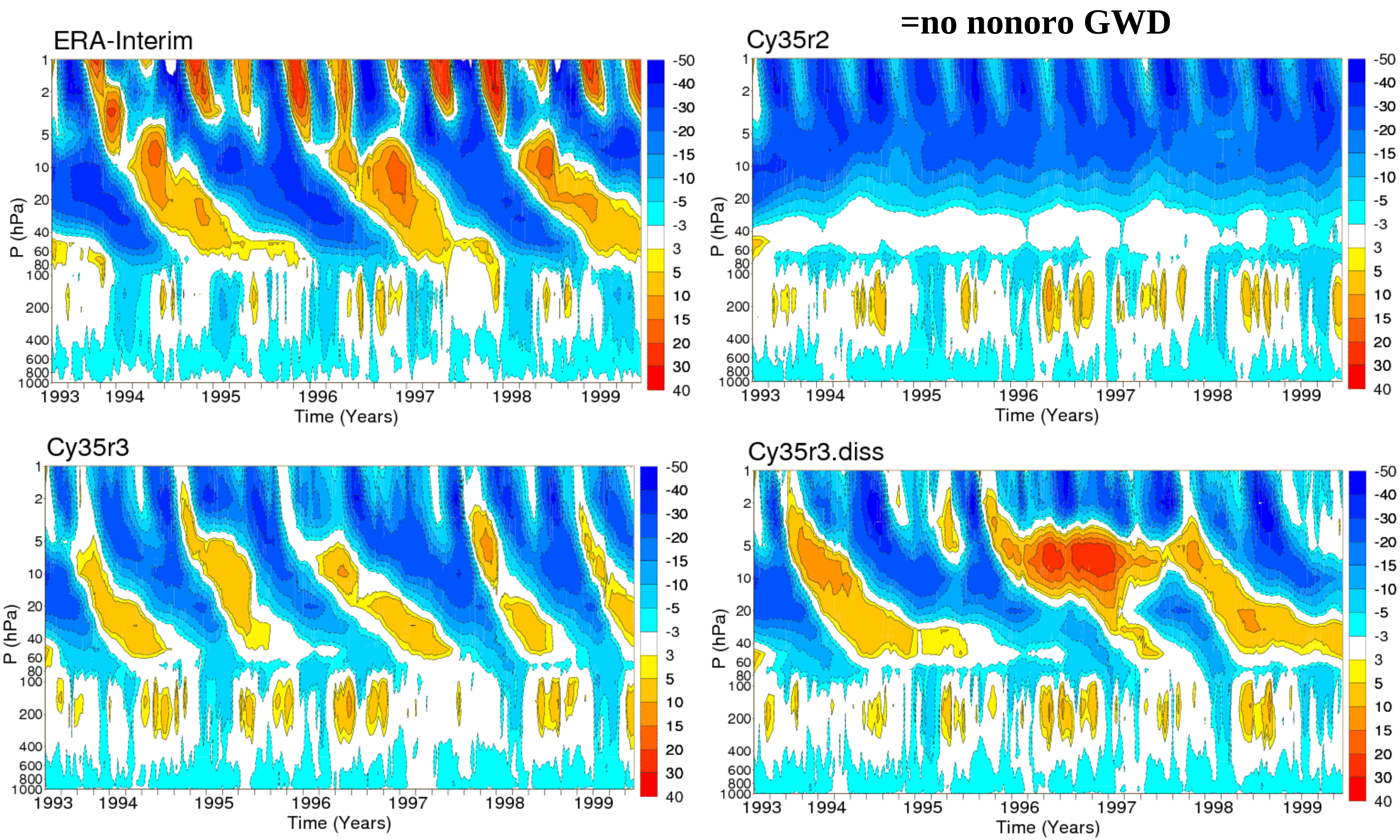
Prominent oscillations in the tropical middle atmosphere are

- A quasi bi-annual oscillation in the stratosphere, and a
- Semi-annual oscillation in the upper stratosphere and mesosphere

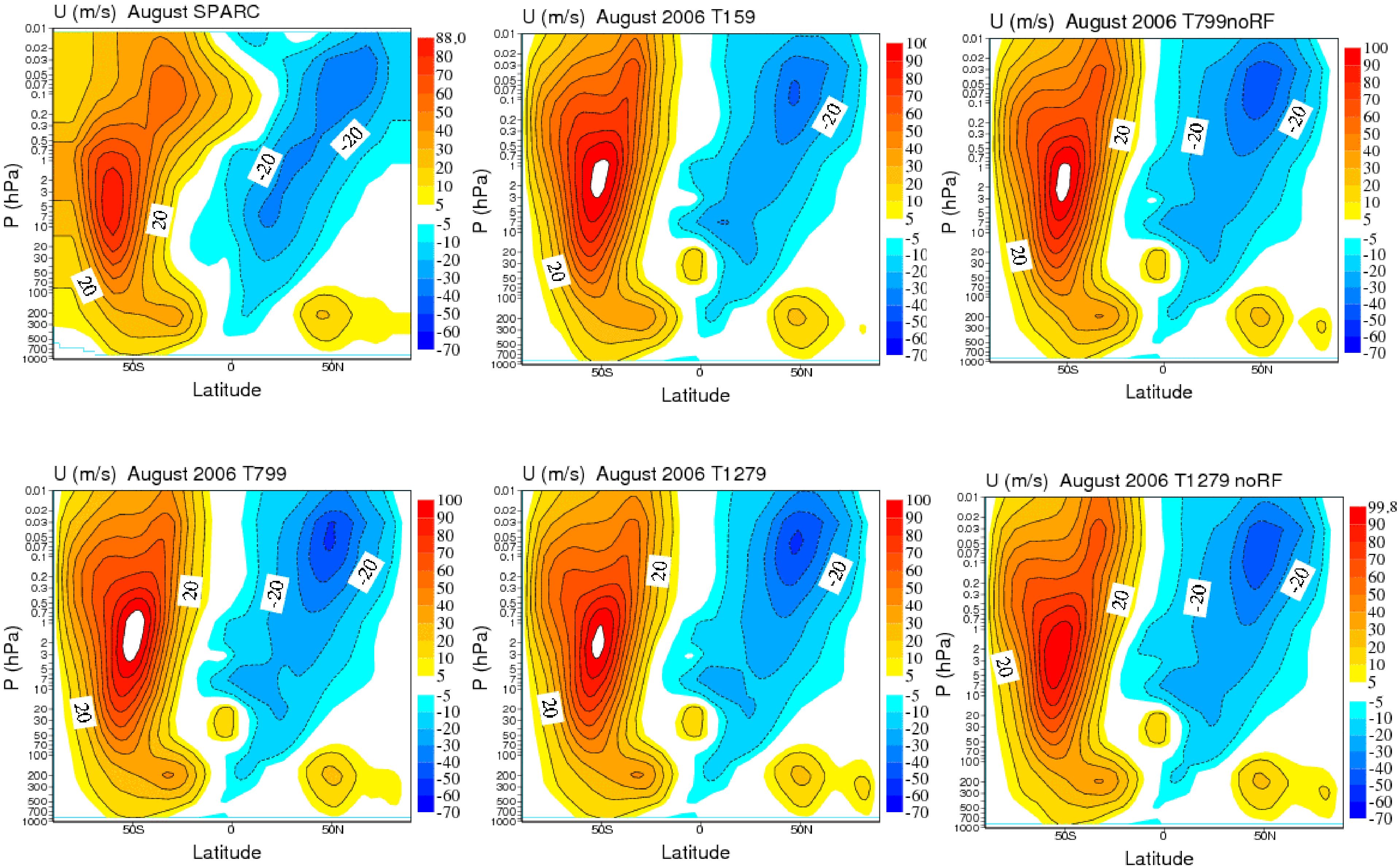
These oscillations are wave induced. Whereas the waves are moving upward, these oscillations propagate downward. Why ? Waves deposit momentum at critical level, wind changes, and so does the critical level, etc

In the following 4-year integrations are carried out with Cy35r2, Cy35r3, and one sensitivity experiment with Cy35r3, but shifting the saturation spectrum to the right ->shifting wave braking to higher altitudes.

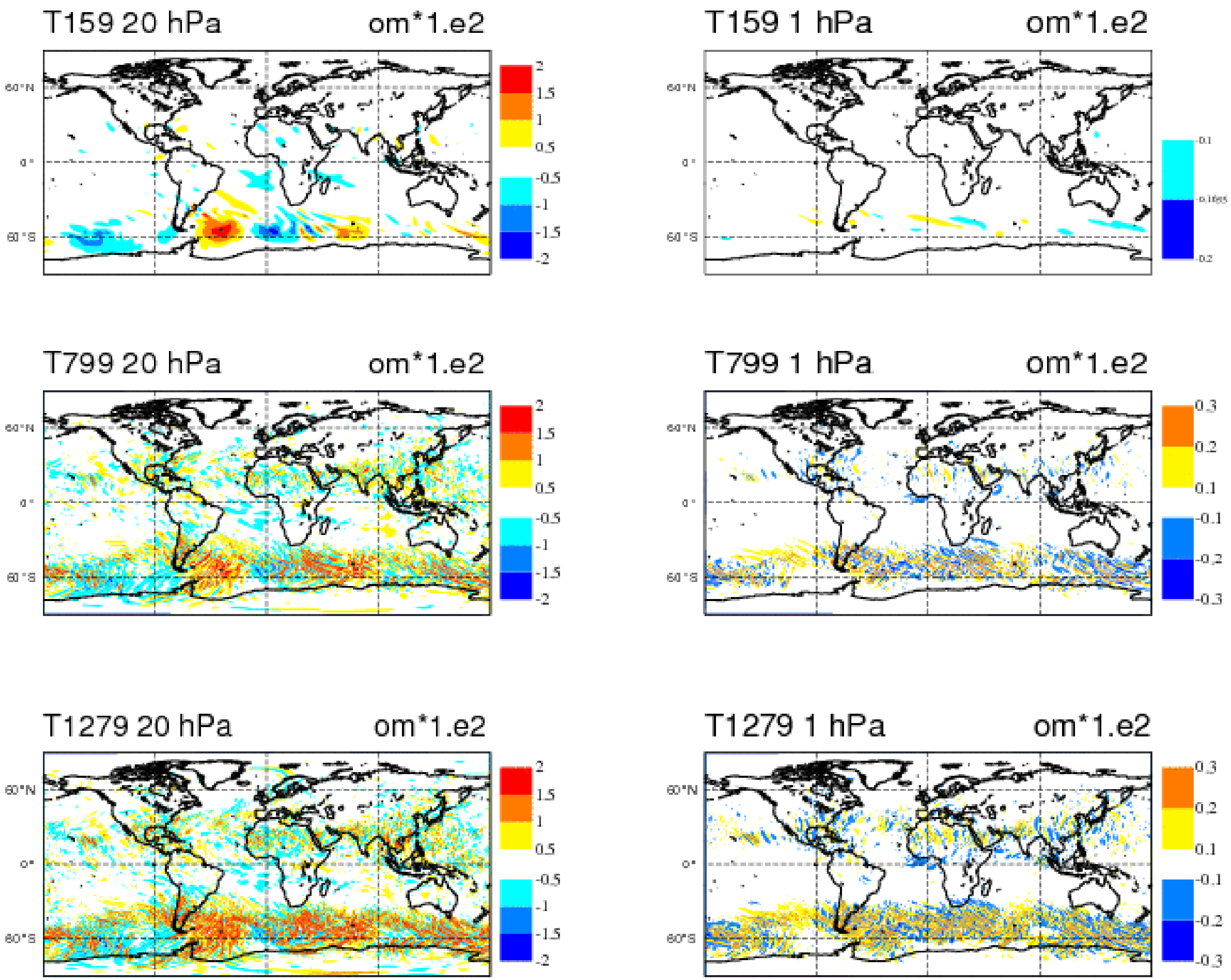
QBO : Hovmöller from free 6y integrations



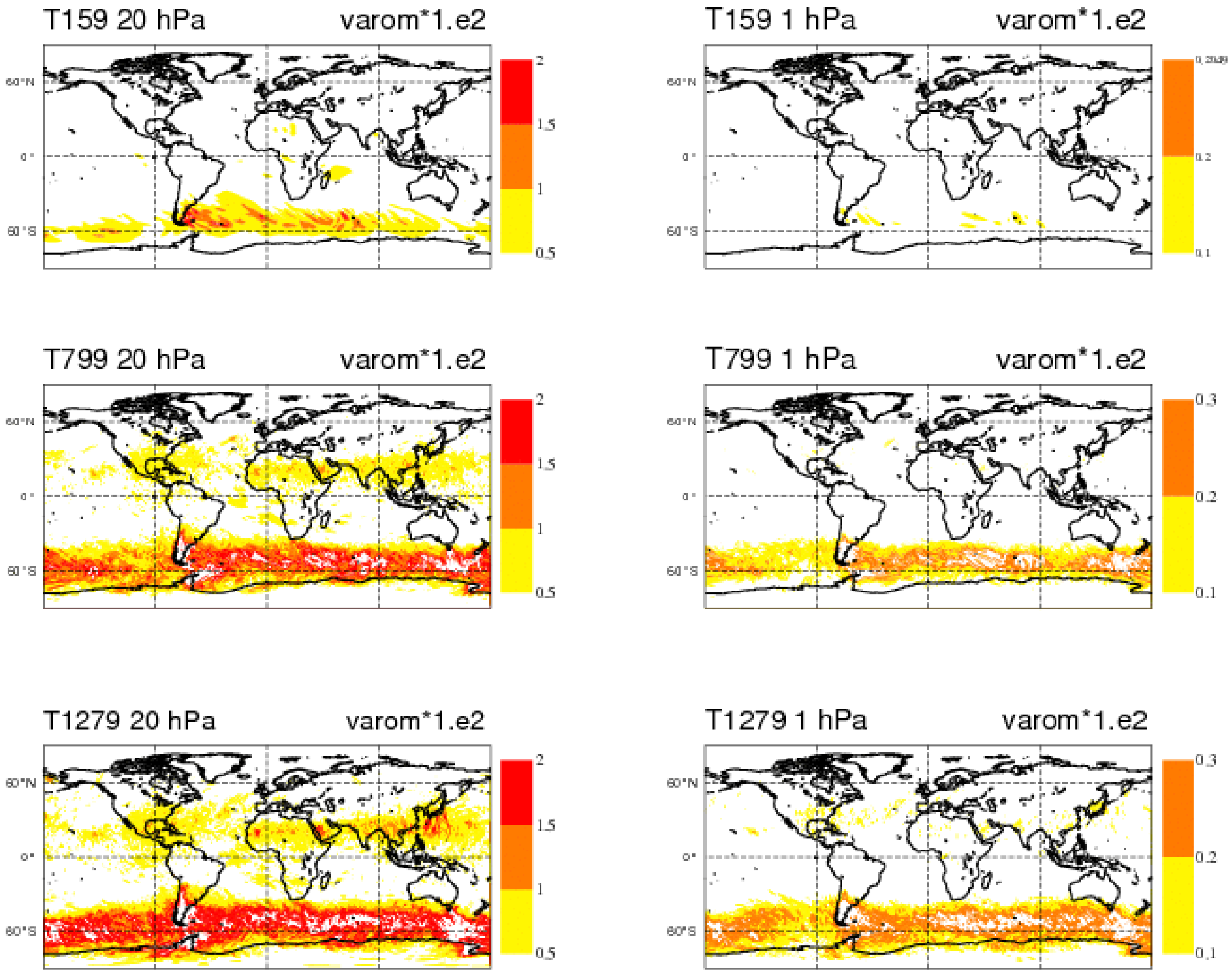
Resolution dependence Cy35r3 (1) August



Resolution dependence (2) Omega (Pa/s) August 2006 day 4



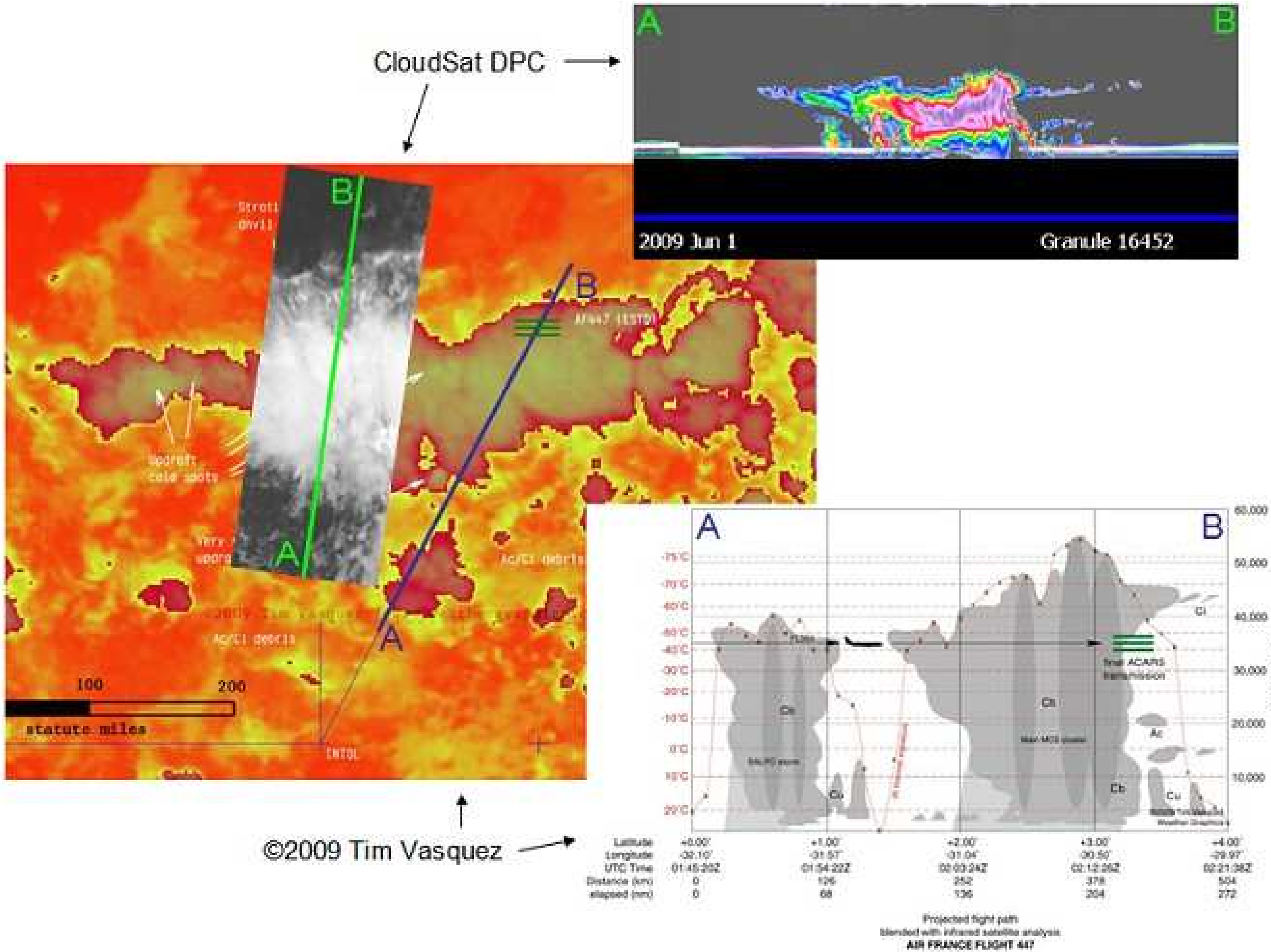
Resolution dependence (4) Monthly mean amplitude Om (Pa/s) August 2006



- Predictability of mesoscale convective systems? Initial conditions, difficult if forcing weak
- Because of dependence on boundary conditions very good large-scale model always necessary … or global model with variable resolution because of assim?
- How does this influence longer-range forecasts (results so far? Not negative? Or not too negatively?)
- Diurnal cycle
- Some high-resolution global runs (explicit convection) show more variability (waves), is there evidence that the climate is also better?

Methods for data assimilation

- If 4D-Var do TL/AD keep up with always more complicated non-linear physics in forecast model
- Ensemble methods, costly
- Simple nudging, benefit in time very limited
- 4DVar (long window) versus ENKF
- Assimilation of precip (radar), or is asssimilation of water vapor from geostationary in cloudy regions not much more promissing
- shouldn't the assimilation be always global (see example tropical cyclones, importance of first inner loop)



CloudSat DPC
A
B
2009 Jun 1
Granule 16452
AF447 (ESTD)
Updraft cold spots
Ac/Ci debris
100
200
statute miles
INTOL
©2009 Tim Vasquez
Latitude
Longitude
UTC Time
Distance (km)
elapsed (nm)
+0.00' -30.10' 01:45:20Z 0 0
+1.00' -31.57' 01:54:22Z 126 68
+2.00' -31.04' 02:03:24Z 252 136
+3.00' -30.50' 02:12:26Z 378 204
+4.00' -29.97' 02:21:36Z 504 272
final ACARS transmission
Cb
Cu
Ac
Ci
Main MCS cluster
60,000
50,000
40,000
30,000
20,000
10,000
Altitude (ft MSL)
Projected flight path
blended with infrared satellite analysis
AIR FRANCE FLIGHT 447